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# LONDON WATER.

## A REVIEW

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OF THE PRESENT CONDITION AND SUGGESTED
IMPROVEMENTS

OF

## THE METROPOLITAN WATER SUPPLY.

BY

A. DE C. SCOTT,
MAJOR-GENERAL, LATE ROYAL ENGINEERS.

LONDON: CHAPMAN AND HALL,
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# CONTENTS.

## CHAPTER I.

PAGE
PARLIAMENTARY HISTORY OF THE WATER COMPANIES . 1

## CHAPTER II.

THEORY OF THE PHYSIOLOGICAL EFFECT OF POLLUTED WATER . . . . . . . . . . 17

## CHAPTER III.

EVIDENCE OF PATHOGENIC EFFECT OF POLLUTED WATER. 26

## CHAPTER IV.

NATURE OF CHEMICAL ANALYSIS OF WATER AND VALUATION OF INDICATIONS . . . . . . 37

## CHAPTER V.

SEWAGE DEFECATION . . . . . . . . 52

## CHAPTER VI.

CONSERVANCY OF THE THAMES AND THE LEA—ITS RESULTS . . . . . . . . . . 63

## CHAPTER VII.

PAGE
NATURAL AND ARTIFICIAL PURIFICATION OF RIVER WATER . . . . . . . . . . . . 73

## CHAPTER VIII.

GEOLOGY AND HYDROLOGY OF THE THAMES BASIN . . 85

## CHAPTER IX.

VARIOUS SCHEMES FOR THE SUPPLY OF LONDON WITH POTABLE WATER . . . . . . . . 94

## CHAPTER X.

GENERAL CONCLUSIONS . . . . . . . . 107

# INTRODUCTION.

THE leading facts of sanitary science have been so widely diffused that most educated people would now consider it necessary before they became tenants of a house possessing an independent water supply, to make some inquiries regarding the origin of the water, with a view to satisfying themselves that it had not been exposed to pollution by refuse matters incidental to the population around them; and in the case of a well, that infiltration from drains and cesspools had been guarded against. The inhabitant of London, however, usually considers himself absolved from the necessity of personal investigation in this direction. A feeling that as a unit in a vast population under one system of water regulation he is helpless, and must take what water is supplied to him, a vague knowledge that the Government interest themselves in the matter, and are supplied with monthly reports and elaborate analyses showing the condition and quality of the water, and an idea thus engendered that if anything were very wrong something would be done by the authorities, combine to make him in this matter, generally speaking, a waiter on Providence. Moreover, any person of average education who is induced to take an interest in the question, and to enter into it in a spirit of impartial inquiry, finds that he is beset with apparently insurmountable difficulties in attempting to arrive at a conclusion. If he should have time to examine the immense mass of Parliamentary literature which is extant, containing the recorded evidence of scientific men on the London Water Question, and its correlative, that of sewage disposal, and the reports of various Royal Commissions and Committees of the House of Commons, presumably based on that evidence, he becomes at once involved in the mazes of a labyrinth of contradictory assertion, and he is brought face to face with the extraordinary and incomprehensible fact, that similar physical conditions, and similar experiments, result with different persons in a totally different experience. Incidentally he becomes aware of the magnitude, diversity, and intricate ramifications of the vested interests which are involved, and which naturally oppose themselves to any indicated change, and he is perhaps led to apply this knowledge, and with considerable effect, to test the quality of the evidence adduced. But more probably he is discouraged at his inability to detect fallacies which he knows must lurk somewhere, and abandons his inquest in despair.

This general apathy, this abandonment of a public question of vital importance, has led unfortunately to an enormous sacrifice of the public interests, and to no inconsiderable loss of human life. In the absence of the propulsive effect of public interest and opinion, administrative action has halted. Commission after commission has taken evidence and made recommendations, each of which has been in turn disregarded, and a practical, although not legal private monopoly of gigantic dimensions dealing with one of the first necessaries of life has been established.

That there has been in the past, on the part of the central and local administrations, a pernicious inactivity in safeguarding the public of London in the matter of water supply, and a want of comprehension of the difficulties which would be caused by the rapid growth of the present monopoly, is evident when it is considered that the purchase of the undertakings of the water companies was advocated by the General Board of Health and by Royal Commissions in 1850, 1869, and 1874, and could have been effected at any one of these dates for a sum less by several millions of pounds than that which would have to be paid at the present time, and for far less at the first than at the last of the dates mentioned; and again, when it is understood that the Thames was condemned as a source of water supply by the Royal Commissions of 1828, 1851, and 1874, and that much of the mortality during the cholera epidemics which visited London some years ago was undoubtedly due to the fact that the supply of water was derived from rivers draining basins inhabited by an infected population.

The question of the suitability of the river water for the supply of the metropolis has been a subject of dispute amongst scientific men for more than half a century, and there seems to be no prospect of an agreement even as to the indications of similar experiments. It is time, therefore, that practical men and the consumers generally should take upon themselves to decide the question by a common-sense appreciation, so to speak, of the evidence which is adduced on either side.

In the following pages the writer has attempted to collect and compress within reasonable limits the chief facts, historical, physical, and scientific, which bear upon the question at issue, and has in doing so made free use of the labours and investigations of eminent scientific men. The only faculties which he can claim to have exercised are those of discrimination in the selection of materials, and general appreciation of the value of available evidence, due to education for, and long experience in, the varied duties of a scientific profession.

If the publication of this paper should result in an increase in the number of those who are able to take an intelligent and active interest in the question of the water supply of the metropolis, the object of the writer will have been attained.

He takes the opportunity of recording his obligations to Professor Frankland, F.R.S., Water Analyst to the Local Government Board; Colonel Sir Frank Bolton, the Metropolitan Water Examiner; and Major Lamorock Flower, the Sanitary Engineer to the Lea Conservancy Board. To the former for his kindness in perusing and criticizing the manuscript, to the latter gentlemen for the information which they courteously and readily supplied, respecting their several charges.

# LONDON WATER.

## CHAPTER I.

### PARLIAMENTARY HISTORY OF THE WATER COMPANIES.

Rise and growth of water companies—Sources of supply—Anxiety as to condition of Thames and Lea—Questions at issue—Royal Commission of 1828—Changes in consequence of report of Commission—Opinions developed by cholera epidemic of 1849—Royal Commission of 1851 on water supply—Their report—Regulating Act of 1852—Removal of intakes of companies above tidal influence—Favourable results—Rivers Pollution Commission report on Thames and Lea—Thames Conservancy Act, 1866—Cholera epidemic of 1866—Mr. Ayrton's Committee—Their report—Lea Conservancy Act, 1868—Royal Commission on water supply of 1867—Scope of inquiry of Commission—Projects of water supply examined by them—Report of the Commission—Second Rivers Pollution Commission—Scope of their inquiries and number of reports—Their Sixth Report—Water Supply and Purchase Bills of Metropolitan Board of Works, 1876—Government measure for purchase of water companies' undertakings, 1880—Committee of inquiry thereon—Report of Committee—Water Bill of the Metropolitan Board of Works, 1884.

[1] METROPOLITAN London uses daily on the average about 146,130,000 gallons of water, in addition to the supply derived from private wells. This daily delivery would in one year fill a reservoir seven miles long, four and a half miles wide, and ten feet deep, and represents a consumption of 30 gallons per head of the population, and 227 gallons per house, per diem.

Eight private companies supply this water to the vast population within the metropolitan area, numbering at the end of 1882 about 4,766,763 persons, occupying 643,752 houses.[2] These companies possess, in the aggregate, within the metropolis 2966 miles of mains, 466 acres of subsidence and storage reservoirs, 95 acres of filter beds, 49 covered reservoirs for the storage of filtered water, 144 engines with an aggregate of 16,610 horse-power. Their capital outlay to the end of 1882 amounted to 13,093,741*l.*, their receipts, exclusive of balances brought forward, to 1,576,255*l.*, their net revenue to 856,757*l.*

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[1] Report of the Local Government Board for the year 1882: Report of water examiner.

This immense multiple organization represents the growth of 230 years, dating from the construction of the New River by Sir Hugh Myddleton in 1613. It has been gradually evolved by the necessities of the continually increasing population, and has acquired extensive privileges by legislative enactment, and as each individual company has practically, although not legally, a monopoly of supply within its own district, it wields powers which place each individual Londoner at its mercy. In their development the companies have exemplified the law of growth which is common to such bodies. Inception, encroachment on the territory of another company, reprisals and a war of rates, and finally combination against the public, are ordinary phases of existence which have succeeded each other with the customary regularity; and now the process of dissolution and absorption by the State is looming in the distance.

The correct appraisement of the value of the possessions of the companies is, however, a necessary preliminary to purchase, and that value, whether as based on the quality of the water supplied, or the price which the companies are privileged to charge for it, has been of late years loudly and strongly impugned.[3]

Five of the London water companies, viz. the West Middlesex

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[2] Metropolitan and City Police Districts.

[3] Report of Parliamentary Committee on provisional agreement for purchase of water companies' undertakings, with evidence, June, 1880.

Grand Junction, Southwark and Vauxhall, Lambeth and Chelsea companies, draw their supplies from the Thames at Hampton and Molesey. The East London Company take their supplies almost entirely from the River Lea at Ponders End, but have an alternative intake on the Thames at Sunbury. The New River Company derive their water from springs in Hertfordshire, and from the River Lea at Ware. The Kent Company pumps exclusively from deep wells sunk into the chalk. Of the whole metropolitan supply about 88 per cent. is obtained from the rivers Thames and Lea, 50 per cent. from the former, and 38 per cent. from the latter.

For a number of years past the condition of these rivers and their tributaries, and their fitness to act as sources of supply of potable water to the metropolis, have been subjects of anxious inquiry and discussion.[4] Draining as they do thickly inhabited areas, with a population aggregating above the intakes of the companies at least 1,270,000 persons, they are exposed to the risk of pollution throughout the whole of their course. The continuous and rapid increase of population tends year by year to intensify the evil, and while optimists contend that sufficient remedial measures have been applied, and that there is no immediate or even proximate necessity for a change, they are fain to admit that it is only a question of time as to when these rivers must of necessity be abandoned. On the other hand there are numbers of persons who are strongly of opinion that the use of such water for drinking purposes is an ever-present element of danger, and that there exists urgent necessity for the substitution without delay of a supply from other and unimpeachable sources.

The rate of increase of the population in the basin of the Thames has been progressive during the past fifty years, and the growing pollution of that river, and its tributary the Lea, early attracted attention. In 1828 seven companies supplied water to the metropolis, the whole of which was pumped from parts of the rivers within the influence of the tide, i.e. from Chelsea downwards, and this was delivered in an unfiltered state to the population.

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[4] Report of Royal Commission on Water Supply, 1828; ditto, Board of Health, 1850; ditto, Royal Commission on Water Supply, 1851; First Report of Rivers Pollution Commission, 1866; Second ditto, 1867; Commission on Water Supply, 1869; Rivers Pollution Commission Report of 1874.

In that year a commission, which was appointed to report on the quality of the water, expressed an unfavourable opinion of it, and in consequence of this the first steps were taken by the companies to filter and otherwise improve the supply. The New River Company constructed extensive settling reservoirs, and their example was followed by the West Middlesex Company. The Grand Junction Company removed their intake from Chelsea to Brentford and formed filters there. The East London Company went higher up the Lea. The Southwark and Vauxhall Company coalesced and established new works at Battersea. The Lambeth Company formed elevated reservoirs at Brixton Hill and Streatham to improve the service generally. It was notwithstanding considered necessary to look out for a new source of supply, and in 1834 Mr. Telford, who was employed for the purpose, advised that the northern portion of the metropolis should be supplied from the Verulam above Watford, and the southern part from the Wandle. Nothing, however, resulted.

In succeeding years, the increase of population and manufactures, the development of drainage, and the abolition of cesspools, increased the pollution to a large extent. It was found that the water in the river was becoming so contaminated as to be beyond purification by ordinary means. In 1849 there was a severe outbreak of cholera in the metropolis, and an opinion, originating with the late Dr. Snow, was beginning to prevail, that impure water favoured the spread of the disease. Inquiry, with the prospect of legislation, was imminent. The Lambeth Company took the initiative, and, having obtained an authorizing Act, moved their intake to a point on the Thames just above Kingston and out of the influence of the tide, and supplied water from thence in 1851. Meanwhile, in 1850, the Board of Health issued a report pointing out the evil of drawing water from the tideway owing to the sewage contamination, condemning the Thames entirely, on account chiefly of its hardness, and recommending that the drainage water from an area of 150 square miles, formed by the Bagshot sands and the lower green sands in Surrey, should be substituted.

In 1851 a commission, consisting of Professor Graham, F.R.S., Dr. Miller, F.R.S., and Dr. Hofmann, F.R.S., was appointed to investigate the quality of the water supply, as also to consider the report of the Board of Health, and the proposal of the London Spring-Water Company to bring water from springs in the chalk in the neighbourhood of Watford. In their report, the commissioners pointed out that the contamination of the rivers Thames and Lea could not fail to become considerable and extensive with the increase of population, and that it appeared to be only a question of time when the sense of the violation of the purity of the rivers would decide the public mind to their entire abandonment as sources of supply, unless, indeed, artificial means of purification were in the meantime devised and applied. They admitted the contamination of the water with sewage, and represented it as a serious evil, but did not condemn the water absolutely, although they clearly doubted the rapid destruction of the contaminating matter. They described the water as clear, bright, and palatable after filtration, and reasonably safe if taken above the influence of the tides. They condemned the scheme of the Board of Health, but considered the proposed supply from Watford preferable to any other, if the hardness of the water could be reduced by any simple chemical process.

The result of these investigations, coupled with the impression made by the great mortality, due to the cholera outbreak of 1849, led the Government to introduce a Bill for the amalgamation of all the companies, with a clause giving power to the Secretary of State, to prescribe the source whence the supply was to be obtained. In consequence of the strong opposition to the Bill, a compromise was effected, and an Act[6] was passed to make better provision for the supply of water to the metropolis, and received the royal assent on the 1st of July, 1852. This Act made it unlawful for any company supplying water to take such water from any part of the Thames below Teddington Lock, or from any of the tributary streams within the range of the tide. The immediate consequence was the removal of the intakes of all the water companies drawing water from the Thames, to places above Teddington Lock, while the East London Company transferred its pumping works on the Lea to Ponders End, above the reach of the tide. The result of all these changes, and the construction of new works, rendered necessary by the Act of 1852, which are said to have cost the companies 2,500,000*l.*, was a very considerable decrease in the amount of organic matter present in the water. This was attributed partly to the change of intakes, but in a great degree also to improvement in the collection, filtration, and general management of the metropolitan water supply.

The next inquiry of an important character, into the condition of the Thames and the Lea, as affecting the water supply, was that undertaken by the first Rivers Pollution Commission in 1865-66 and concluded in 1867. As regards the Thames, the commissioners depicted in forcible language the extreme pollution of that river. They remarked that the sewage of hundreds of thousands of persons entered it, that the process of oxidation sustained in the water by organic matter was no sufficient guarantee for the elimination of the sewage taint, that the Thames water was open in kind if not in degree to the same objections as well water, infiltrated by liquid from an adjoining cesspool, and that the river was, moreover, fouled by refuse from paper-mills and tanneries, as also by floating carcasses of animals. Their statements in regard to the pollution of the Lea were equally strong. In the case of both rivers they made recommendations

[6] 15 and 16 Vict. cap. 84.

with a view to remedying the evils noticed, and advocated the application of the sewage to land, which they appeared to consider would be equivalent to excluding it from the rivers. These recommendations bore immediate fruit, for on the 6th of August, 1866, the Thames Conservancy Act (29 and 30 Vict. cap. 89) was passed. By this Act the powers of the existing Conservancy Board were enlarged, and their jurisdiction extended up to Cricklade in Wilts; it was directed that the surface of the river should be effectually scavenged, and the admission of sewage or other offensive or injurious matter into the Thames, or into any tributary stream or water-course, within three miles of its junction with the Thames, was prohibited under heavy penalties.

In 1866 there was a severe outbreak of cholera in the East of London, and in 1867, in consequence of suspicions that the quality of the water supplied to that quarter of the metropolis had had some connection with the outbreak, instructions were given by the House of Commons to a select committee, of which Mr. Ayrton was chairman, to inquire generally into the operation and results of the Metropolis Water Act of 1852. This committee reported, that they were so far satisfied with the quantity and quality of the water supplied from the Thames, that they did not consider there was any ground for disturbing the arrangements made under the Act of 1852. The water of the Lea they considered wholesome, and comparing favourably with that supplied to other places. They agreed with the Rivers Pollution Commissioners that it was liable to serious pollution, suggested certain modifications of the measures that commission proposed to remedy the evil, and expressed an opinion that when these were carried out, the water supplied by the companies would be of unexceptionable quality. They recommended constant supply, with strict provisions to prevent waste, and that on the Metropolitan Board of Works should be imposed the duty of seeing that the companies fulfilled their obligations.

It may here be stated that in consequence of these reports, an Act (31 and 32 Vict. cap. 154) was passed in 1868, to make better provision for the preservation and improvement of the River Lea and its tributaries, which was analogous in its terms to the Thames Conservancy Act.

In 1867 a commission was appointed, under the presidency of the Duke of Richmond, to ascertain what supply of unpolluted and wholesome water could be obtained, by collecting and storing water in the high grounds of England and Wales, and to report which of such sources were best suited for the supply of the metropolis, and how the supply from the remaining sources could be most beneficially distributed amongst the principal towns. The question as to whether there were other districts in addition to the high districts of England and Wales, from which a good supply of unpolluted and wholesome water could be obtained, was also referred to it. It was also to inquire into the water supply of the metropolis generally.

The inquiries of the commission were practically limited to the water supply of the metropolis, as it was soon seen that the question of the supply to the provincial towns was so large, that it would have been the work of years to investigate. The report bears date, the 9th of June, 1869.

The commissioners examined witnesses and received evidence regarding various schemes for the supply of water to London from places outside the Thames basin, viz. a project by Mr. Bateman, C.E., for storing and conveying water from the mountainous districts of Wales; one by Messrs. Hemans and Hassard of a similar character for supplying water from the lakes of Cumberland and Westmoreland; Mr. Hamilton Fulton's plan for taking water from the upper sources of the Wye in Mid-Wales; that of Mr. George Remington, proposing to draw a supply from the hills of Derbyshire.

Of projects dealing with the Thames, or sources within the Thames basin, they had before them those of Messrs. McClean, Mr. Bailey Denton, Mr. Brown, and Mr. Bravender, which dealt with the Thames and its tributaries, and also Mr. Mylne's scheme for storing water in the upper basin of the Lea. They further took notice of suggestions made by the Rev. Mr. Clutterbuck and Messrs. Homersham, P. W. Barlow, and Meeson, for procuring water from springs in the chalk or wells in the chalk and oolite.

Other gentlemen, viz. Messrs. Thomas Hannell, G. W. Ewens, and Telford McNeil, came forward with proposals for the utilization of the chalk, and Bagshot sands near Basingstoke and Farnham, as well as chalk springs near Havant, as sources of supply.

These projects and the conclusions of the commissioners respecting them, will be noticed further on. It may here be remarked, however, that they objected generally to schemes which were based on sources outside the Thames basin, because they held that the latter contained a sufficient supply of water for all possible contingencies, provided that the ordinary volume of the Thames and the Lea were supplemented by storage reservoirs for flood water, and that the subterranean water from the chalk to the south and south-east of London, and from the green sand, were utilized. In regard to quality, they stated that there was no evidence to lead them to suppose that the water supplied by the companies was not generally good and wholesome; that its hardness constituted no vital objection to its use for general, household, and manufacturing purposes; that filtration was essentially necessary to secure good quality, and was susceptible of improvement, as it was in many cases imperfectly carried out; that when efficient measures for excluding the sewage and other pollution from the Thames, and the Lea, and their tributaries, and for ensuring perfect filtration were adopted, water taken from the present sources would be perfectly wholesome, and of suitable quality for the supply of the metropolis.

As to quantity, the commissioners estimated that a population of from 4,500,000 to 5,000,000 would probably have to be provided for, though they believed the time for such extended provisions would be very remote. They calculated that 200,000,000 gallons per day was the highest demand which need reasonably be looked forward to for the metropolitan supply. They recommended that the constant service system should be promptly introduced, and as it could not in their opinion be effectually introduced so long as the supply remained in the hands of private companies, and for other and general reasons, they recommended the constitution of a public body with full powers in respect of water supply, rating, and the purchase of the existing works.

The commission appointed on the 18th of May, 1865, to inquire into the pollution of rivers, and which presented reports on the state of the Thames and the Lea in 1866-67, was dissolved on the 4th of February, 1868. It consisted of Mr. R. Rawlinson, C.B., Mem. Inst. C.E., Mr. John Harrison, Mem. Inst. C.E., and Mr. Thomas Way, late Consulting Chemist to the Royal Agricultural Society. On the 6th of April, 1868, a new commission was issued, appointing Col. Sir Wm. Denison, R.E., Dr. Edward Frankland, F.R.S., and Mr. John Chalmers Norton, for the purpose of inquiring how far the present use of rivers for the purpose of carrying off the sewage of towns and populous places, and the refuse arising from industrial processes, could be prevented without risk to public health or injury to such processes and manufactures, and how far such sewage and refuse could be utilized and got rid of, otherwise than by discharge into rivers and running waters, or rendered harmless before reaching them. Also for the purpose of inquiring into the effect on the drainage of lands and inhabited places, of obstructions to the natural flow of rivers and streams caused by locks, weirs, and other navigation works, and the best manner of remedying any evils thence resulting.

By subsequent instructions dated the 29th of April, 1868, the scope of the commission was extended so as to include the question of water supply, as well as to inquire into the condition of various rivers and streams in England and Scotland.

The commissioners issued six reports relating to the various questions referred to them. In their Sixth Report, signed on the

30th June, 1874, they dealt with the domestic water supply of Great Britain, and their report was based on inquiries extending over a period of six years. A considerable portion of it is devoted to the question of the water supply of the metropolis, and the following is a summary of their conclusions thereon.

As to the quality of the water which is derived from the Thames:—

1. The Thames above the intakes of the respective water companies receives the sewage from a large number of towns and inhabited places, the washings of a large area of highly cultivated land, and the filthy discharges from many industrial processes and manufactures.

2. The river is used for bathing; for the washing of sheep and cattle and of dirty linen, and the putrid carcasses of animals float upon its surface. It is the common waterway for a large amount of polluting matter, much of which is at times dangerous to the health of the persons who use the filtered water for dietetic purposes.

3. In times of flood a large proportion both of the suspended and dissolved filth is conveyed down to the intakes of the metropolitan water companies, and in ordinary weather a considerable proportion of the soluble organic matter of sewage discharged into the river and its tributaries likewise makes its way down to the works of the water companies, and is still present in the water distributed by them in London.

4. The water is nevertheless, when efficiently filtered, free from any offensive taste or odour.

5. Notwithstanding the application of partial remedies for sewage pollution at Banbury, Eton, and Windsor, and the greater care exercised by most of the companies in the storage and filtration of water, the organic pollution contained in the Thames water delivered in London, though subject to fluctuation from the greater or less prevalence of floods, does not diminish.

6. There is no hope of this disgusting state of the river being so

far remedied as to prevent the admixture of animal and other offensive matters with the filtered Thames water, as delivered in the Metropolis.

7. The temperature of the water drawn from the companies' mains is liable to excessive fluctuation, being near freezing-point in winter, and so high in summer as to render the water vapid and unpalatable.

The commissioners recommended that the Thames should as early as possible be abandoned as a source of water for domestic use, and that the sanction of the Government should in future be withheld from all schemes involving the expenditure of more capital for the supply of Thames water to the metropolis.

As to the quality of the water supplied from the Lea, they reported:—

1. That the pollution of the Lea above the intakes of the water companies was similar in character to that of the Thames, but considerably less intense.

2. That sewage and other disgusting matters reached the intake of the metropolitan water companies drawing from this river, and that the soluble portions of such matters were not wholly eliminated by the efficient filtration to which the water was subjected before delivery.

3. That the water of the Lea was slowly though irregularly deteriorating from year to year, and that there was no hope of purifying it to such an extent as to render it at all times safe for domestic use.

4. That the Lea should also be abandoned as a source of potable water. That measure was less urgent than the abandonment of the Thames water, but the sanction of the Government should not be accorded to any further expenditure of capital upon the supply of Lea water to the metropolis.

5. That nothing would be gained by the abstraction of the water at any higher points short of the springs forming the sources of the tributaries of these rivers.

The commissioners expressed high approval of the water supplied to London from deep wells in the chalk, and advocated the continued and extended supply of this and similar water to the metropolis. They further stated that abundance of spring and deep well water could be procured in the basin of the Thames and within a moderate distance of London, and recommended that the metropolis should be exclusively supplied on the constant system with such water, softened before delivery with lime.

They considered that the introduction of the new supply would render it necessary either to throw open the metropolis water supply to new companies, or to transfer the control of that supply to a responsible public body invested with the necessary powers for the purchase of the existing works, and the construction of such other works as might be necessary, and they recommended the last alternative.

They were of opinion that the proposed supply of water from North Wales and from the Lakes of Cumberland was unnecessary, but that both these schemes were capable of furnishing the metropolis with an abundant supply of excellent water. The cost, however, would be very large.

During the parliamentary session of 1878 a Bill was promoted by the Metropolitan Board of Works, in view to sanction being given to a scheme for obtaining a supply of spring water to the amount of 16,000,000 gallons daily, by means of wells and borings at different points around London. This water it was proposed to pump to reservoirs situated at a considerable height, and to distribute through the metropolis by a set of mains entirely separate from those through which the present water is supplied. The Board at the same time brought in a Bill for the purchase of the water companies. The latter was strongly opposed and subsequently withdrawn, and the former was not persevered with in consequence of the disfavour with which it was viewed by the various local authorities, and also because its success depended on the acquisition by the Board of Works of the control of the whole water supply.

In March, 1880, the then Home Secretary introduced a measure for the purchase of the existing water companies, and in June, 1880, a select committee was appointed to inquire into the expediency of acquiring the undertakings; also how far the agreements provisionally entered into by the Government would furnish a satisfactory basis for purchase, and as to the nature and extent of the powers of the companies to levy water-rates, and how far it was desirable to modify them.

The committee reported that it was expedient that the supply of water to the metropolis should be placed under the control of a public body, which would represent the interests and command the confidence of the consumers. That the water authority should be vested with statutory powers to acquire and utilize as far as deemed expedient existing sources of supply, and have recourse to other sources as might prove available and desirable. That such water authority should be a representative body, and that a Bill constituting it should be introduced at an early date by the Government. That it should include elements from the Corporation of London, the Metropolitan Board of Works, and from among the representatives of districts outside the metropolis at present supplied by the metropolitan water companies. The source, nature, and price of supply would be decided by the body so constituted. They stated that it would be desirable, at least for certain purposes, to acquire the undertakings of the existing companies, if the same could be obtained on fair and reasonable terms. They gave in abstract the amounts to be paid under the provisional agreements as follows:—

The immediate annuities to be paid amounted to 773,454*l.*; to this were to be added deferred annuities to accrue by way of increments at various intervals, amounting finally to 325,449*l.*, making an ultimate annual payment of 1,098,953*l.* The value of the immediate annuities in 3½ per Cent. Stock at par was

22,098,700*l.* The present value of the deferred annuities capitalized on the same basis would be 7,635,581*l.*, and the total 29,734,281*l.* But in addition to this, provision was to be made for the debt charges, viz. preference and debenture capital, 3,061,500*l.*, with an annual charge for interest of 133,913*l.*, and also bond and mortgage debt, 223,055*l.*, with an annual charge of 7807*l.* Adding these charges the annual payment would amount to 1,240,673*l.*, and the total capital value to 33,018,836*l.*

The arrangement was based on the understanding that so much was to be paid by way of immediate annuity on account of the actual net income of the companies, and so much in deferred annuity on account of the anticipated increase of revenue from year to year. The immediate income was based on the net revenue as estimated to accrue for the year ending the 1st of June, 1881.

The committee pointed out that the calculation of increments was founded on the assumption that all items of receipt would grow at a greater rate in the future than in the past, and that the growth of capital expenditure, which had hitherto followed with increase of income, would sink almost to nothing, and might be discarded from calculation, and they expressed their opinion that such assumptions do not afford a sound basis for a financial estimate of future results.

Alluding to the objections raised to the terms of the proposed purchase by the Corporation of London and the Metropolitan Board of Works, they stated their concurrence therewith.

It was noted that the Corporation of London had asserted that the price agreed upon was nearly 9,000,000*l.* in excess of the market value of the property, at a period immediately antecedent to the negotiations.

The committee further observed that the companies had raised their rates in recent times under their statutory powers, and that such increases following growth in the value of houses had no legal relation to the quality or quantity of the supply. The companies' claims to escape from the restriction laid down by statute (Water Works Clauses Act of 1847), which limits the dividends to 10 per cent. on the paid up capital, and directs that surplus profits are to go towards reduction of price, on the ground that they have by the same statute a right to back dividends until a sum had been paid representing the aggregate of 10 per cent. per annum on the paid up capital, from the date of the formation of each company, the committee characterized as intolerable. One estimate of the sums so claimed amounted to 2,000,000*l.*, and in the case of the New River Company it has been put forward that the back dividends due amounted to 15,000,000*l.*

The committee laid stress on the fact that the total cost of the existing water supply had not exceeded 12,000,000*l.*, a considerable portion of which sum had, however, been expended on useless or reduplicated works, and they pointed out that it would be a question for the water authority to decide whether a new and better supply could not be obtained at a cost greatly less than would have to be paid under agreement with the companies.

The recommendations of the committee have not yet borne fruit. In the early part of the current session of Parliament (1884) the Metropolitan Board of Works endeavoured to obtain the passage of a Bill compelling the water companies to supply water by meter if required to do so by a consumer, providing that in other cases the decision in the case of Dobbs *v.* the Grand Junction Company, should regulate the charges throughout the entire area of the water companies' districts, limiting the payment of back dividends to six years, and directing that if additional capital were required it should be raised by selling shares at auction. This Bill was thrown out on the second reading.

## CHAPTER II.

### THEORY OF THE PHYSIOLOGICAL EFFECT OF POLLUTED WATER.

Arguments used against the abandonment of the Thames and Lea as sources of water supply—Origin of such view—Contention of persons holding opposite views—Traced to reports of Rivers Pollution Commission—Importance of question at issue—Starting-point of inquiry into sanitary conditions of human life—Facts derived from Registrar-General's reports—The germ theory of zymotic disease, how far supported by experiment and by observation—Specific organisms recognized as invariable concomitants of certain diseases—Experimental evidence of connection of each specific organism with a peculiar disease—Artificial cultivation of organisms—Natural history view of theory—Evidence of action of atmosphere as carrier of morbific germs—Variations of disease types—Theory of poisonous qualities of sewer gas—Evidence of existence of unorganized ferments—Katalysis induced by unorganized matter—Germ theory of disease not yet scientifically proved—Practical sanitary work based on facts, and not on theory.

The case of those who contend that the water at present supplied by the London companies is excellent in quality, and who deprecate the abandonment of the Thames and the Lea as sources of supply, is mainly based on the Report of the Royal Commission of 1869. That report, so far as it conveyed approval of the existing supply, appears to have been to a great extent dependent on assertions in evidence given before the Commission, that the admission of sewage and other polluting matters into the Thames and the Lea did not imply the irremediable fouling of the water; that, on the contrary, the organic matter so introduced would in all cases undergo rapid transformation into mineral and innocuous compounds. The advocates of the wholesomeness of the water from the Thames and the Lea contend, in fact, that the direct entry of sewage and polluting refuse from manufactures and other sources into these streams is now practically prevented by the action of the Conservancy Boards; that the so-called purifying power of the running water disposes of organic matter which may in any case reach them; and that, as this purification is supplemented by the action of the subsidence reservoirs and the efficient system of filtration carried out by the companies, there is no sufficient reason to doubt the character of the supply, or to incur the serious expense and risk of failure incidental to the exploitation of any new sources of supply, which have been suggested.

Those who advocate the abandonment of the Thames and the Lea join issue with their opponents on all points. They assert that the conditions obtaining in the basins of the Thames and the Lea render it practically impossible for the Conservancy Boards to prevent extensive pollution of the water; that, in point of fact, the amount of organic matter present in the water, which is the test of pollution, has, on the whole, increased since the Conservancy Boards commenced to interdict the direct flow of sewage into the water-courses; and that the resolution of sewage and organic matter, introduced into flowing water, into innocuous compounds is extremely slow and uncertain. While admitting the purifying effect, to a certain extent, on the river water of storage in subsidence reservoirs and filtration, as uniformly practised by the companies, they contend that, while on the one hand the poisonous qualities of water polluted with sewage or animal matter in certain conditions, known or unknown, has been conclusively proved, on the other we have, in the present state of our knowledge, no means of ascertaining at what point in the subsequent history of the water these poisonous qualities are eliminated; and that, apart from consideration for feelings of delicacy, which revolt at the notions implied, common prudence should lead us to reject water which can be traced to a source which has been contaminated by sewage or organic matter of animal origin. These views may be said to have taken as their origin and point of departure the various reports of the Commissioners appointed to inquire into the pollution of rivers, covering a period of six years, from 1868 to 1874, and particularly the report of 1874, which is in some respects a summary of the whole, and embodies the conclusions arrived at as the result of the study of an enormous mass of evidence and a vast and exhaustive series of investigations and analyses.

The contested question of the pollution of the Thames and the Lea mainly derives its importance from the facts, and in no inconsiderable measure from the theory, of the propagation of some of the zymotic diseases, such as cholera and enteric fever, by means of potable water. No doubt the suggestion of disgusting pollution is apt, apart from the question of disease, to kindle a natural sentiment of aversion, which, if it were supported by the appearance of the water when presented for consumption, would become a factor more powerful than any other in determining the solution of the questions at issue. But as, on the contrary, such water, when it reaches the consumer, is generally inoffensive to the nose and eye, and in fact clear and not unpalatable, the vast majority of persons think it the truest philosophy to dismiss the subject from their minds.

It may be said with much truth that the starting-point in this country of fruitful inquiry into the sanitary conditions of human life was the initiation of the registration of deaths amongst the population at large. This registration, which commenced some forty-six years ago, speedily drew attention to the phenomena of explosions of zymotic disease occurring often within very restricted areas, and the investigations[1] promptly carried out by health officers and inspectors acting under the authority of the Government, as well as by medical practitioners, have thrown much light on the mode of propagation of these diseases, and the conditions which favour their presence and diffusion. The researches of physiologists and chemists have led to the conclusion that such diseases, which occur in epidemic form, diffuse themselves by living germs or spores, which, finding a suitable nidus in the bodies of animals, there multiply and produce that specific disturbance of the normal vital functions which constitutes a disease of the zymotic class.[2] It has been proved by experiments that the active matter of the virus of cow-pox, small-pox, sheep-pox, and glanders, is comprised in the solid and not in the liquid constituents; in the organized particles, and not in the solution or unorganized medium in which the particles are suspended; that the minuter particles pass through all filters; and that inoculation with the most minute quantity of the virus will, if successfully carried out, result in giving as virulent disease as inoculation with a large quantity. Thus the observed facts lead to the theory that the disease is due to the power of self-multiplication of the organized particles, which is called into exercise if only one such particle is successfully introduced into the animal circulation.

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[1] Annual Reports of Local Government Board. Reports of Medical Officer.

We are familiar with the fact that such diseases as small-pox, scarlatina, measles, and typhus fever can apparently be communicated by one person to another, even without contact. In these cases the air is supposed to act as the carrier of the poisonous matter, which is conveyed to the lungs. Numerous investigations have proved that cholera and enteric or typhoid fever can be communicated to previously healthy persons by means of water contaminated by the excretions of persons suffering from these diseases. Here the water conveys the poison to the alimentary canal. Theory asserts that in all these cases the poisonous matter consists essentially of organized bodies, which set up fermentations in the blood, akin to those which produce alcohol from sugar, vinegar from alcohol, and lactic acid from milk, and which, as is well known, are due to organisms which have been identified, and without the presence of which neither fermentation nor putrefaction can ensue. The several specific organisms which are invariably present in cases of tuberculosis, of charbon or splenic fever, and of malarial fever, have been recognized by physiologists. We have the Bacillus tuberculosis of Koch; that of charbon, discovered by Pollender, Brauel, and Davaine; that of marsh fever by Tomasi Crudeli, of Rome, and Klebs, of Prague. The germ theory of disease assigns to these organisms the function of creating the specific diseases; it asserts that they are a cause and not a result of disease, and the results of experiment and observation tend, on the whole, to support the theory.

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[2] Sixth Report of Rivers Pollution Commission. Chauveau, Comptes Rendus de l'Académie des Sciences.

The specific affections which have been cited above, and others of a like nature, such as chicken cholera and swine fever, can be communicated by inoculation with the blood of affected animals containing the bacilli always present in such cases The bacilli can be cultivated in appropriate animal infusions; the infusions containing the cultivation may then possess the virulence of the originally used matter: in other cases their activity may be greatly reduced, or almost obliterated. The result depends on the number of successive cultivations, and the circumstances under which the bacillus is cultivated. By cultivation in the bodies of animals the virus, rendered mild in character, as above explained, may be made to reassume extreme and fatal activity.[3] Those who believe in the germ theory of disease see in these manifestations illustrations of the Darwinian laws relating to the modification of species by the changes in their environment, brought about by external causes. The specific bacillus of malarious fever has been found to be present in the lower strata of the atmosphere of the Agro Romano, as well as in the surface soil and stagnant water. The malaria of the delta of the

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[3] These statements of Professor V. Nägeli, Buchner, and Pasteur are to some extent disputed by Koch and Klein.

Niger River in Africa is blown by the north wind a distance of 100 miles to the island of Princepe, which is thus subjected to epidemics of marsh fever. In malarious countries disturbance of the soil by excavations has been occasionally followed by outbreaks of fever and dysentery. It has been observed that a screen of trees placed to leeward of a miasmatic marsh has had marked effect in intercepting the malaria. The effect of the congregation of large masses of human beings, as at religious festivals in India, in producing a cholera atmosphere, has been repeatedly noticed. We are thus led to the assumption that the morbific germs in certain cases rise cloud-like in the air, and are wafted from place to place in obedience to air currents. The modifications produced in the qualities of the virus of certain diseases by cultivation in various infusions and in living animals, exemplified by Pasteur's experiments, and the recognition herein of the operation of the natural law of the variation of species by external influence, opens a wide field of inference explanatory of observed pathological phenomena. To this cause may be referred variations in the type of diseases, and in the mode in which they diffuse themselves. Cases of non-infectious malarious fever in persons crowded together have resolved themselves into malignant typhus fever. The bilious remittent fever of the African coast, carried in the persons of patients to adjoining islands, has been known to change into infectious continued fever, spreading to the population at large. Our inferences may be still further extended, and we may suppose that innocuous germs do, under certain conditions, vary and assume the specific character which connects them with disease.[4] The successful cultivation of the virus of certain diseases in suitable media renders reasonable the hypothesis that some disease germs, carried with the excreta of patients into sewers or cesspools, and finding there a suitable pabulum, may multiply and give rise to an enormous increase of infectious matter.

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[4] Stated by Nägeli and Buchner to have been experimentally proved by them.

There is reason to believe that the germs of cholera and typhoid fever are of this nature, and that they can propagate themselves equally in the human body, in earth, and in foul water. The diffusion of malarial germs in the air leads us to admit the possibility of the presence of sewer-bred cholera, or typhoid germs in sewer gas, and practical experience tends to favour the same conclusion. Pasteur has stated that when the cultivation of the virus of chicken cholera is carried on in glass tubes, from which the external air has been excluded, the cultivated virus possesses all the virulence of the original matter; but that when cultivation is carried on in open tubes, the virulence of the cultivated matter is much attenuated.[5] Experience has led sanitary engineers to provide for the thorough ventilation of sewers and the rapid dispersion of sewer gas. Practice, governed by experience, is here, in accordance with the teachings of laboratory experiments, based on the germ theory of disease.

[6] The attenuation of the virus of certain diseases by successive cultivation, and the possession, in certain cases, by the attenuated matter of vaccine or protective qualities, is asserted by Professor V. Nägeli, Dr. Hans Buchner, and Pasteur; and the two former appear to accept the proposition that a harmless organism, such as the B. subtilis of hay infusion, can be converted into a pathogenic organism.

On the other hand, Koch and Klein deny the change of quality in the case of B. anthracis and its vaccine property after attenuation, except in the case of sheep, and equally deny the conversion of harmless into poisonous organisms. Moreover, there are facts which cause some pathologists to hesitate in their acceptance of the germ theory of disease. The extraordinary septic properties of some poisons, such as sepsin, the Ptomaines, and some snake poisons, which appear to reside in alkaloids, some of which have been isolated and crystalized, seem to indicate that katalysis, overcoming the resistance due apparently to vital energy, can be induced by unorganized matter, which, initiating the disruption of the complex molecules of the blood, leads to their successive decomposition by interaction, the one on the other in rapid succession. The question which seems to present itself is this: Do the organisms which are present in putrefactions and fermentations, by their inherent power of assimilation, carry out the decomposition of the putrefying or fermenting liquid, or is there a chemical force external to them, and residing in the unorganized matter surrounding them, which starts decomposition in advance, and prepares for the organisms a suitable pabulum, which enables them to multiply? Some pathologists and chemists do not seem to consider that this question has been satisfactorily solved. It is evident that much in connection with this subject still belongs to the region of speculation and theory, and all that has been attempted has been to derive from the writings of the best authorities a view of the present condition of the theory of the propagation of disease by organized bodies.

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[5] Report of Local Government Board, 1880.

[6] Eleventh Report of Local Government Board. Report by Mr. Victor Horsley, M.B., on Septic Bacteria and their Physiological Relations. Report of Dr. E. Klein on the Relation of Pathogenic to Septic Bacteria.

Theory, however, cannot alone furnish a sound basis for practical action. But we have been taught, by observation and by investigations into the sequence of morbific phenomena in hundreds of outbreaks of zymotic disease, that foul air and foul water are associated therewith.[7] It is true that millions of people in this country habitually live in a foul atmosphere, and habitually drink water contaminated with sewage or infiltrations from cesspools and middens, and this without being attacked by typhoid fever; but it is equally certain that in cases far too numerous to specify in detail, it has been established on conclusive evidence that outbreaks of this and other diseases of the same class have been due to those conditions of existence, plus something which those conditions invite, and which theorists call disease germs, but the mere specification of which need not exercise the minds of practical men, provided that they take note of the observed facts, and avoid the dangers which are indicated.

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[7] Reports of Medical Officer to the Local Government Board.

# CHAPTER III.

## EVIDENCE OF PATHOGENIC EFFECT OF POLLUTED WATER.

Danger of river water used for domestic purposes—Cholera epidemics in London—Condition of water supply at the period of each epidemic and mortality from cholera—Report of Dr. Farr—Mortality due to foul water of Southwark and Vauxhall and Lambeth Companies—Investigation—East London cholera epidemic of 1866—Pollution of East London water supply—Broad Street outbreak—Facts rendering investigations into causes of outbreaks difficult—Millbank Prison—Bethlem Hospital—Investigations into outbreaks in provincial towns—Manchester and Salford—Glasgow—Paisley and Hamilton—Salisbury—Margate—Theydenbois—Goodrington and other towns—Calcutta—Propagation of typhoid fever by polluted water—Millbank Prison—Terling—Wicken Bonant—Caterham—Diffusion of some zymotic diseases by means of milk—Normal prevalence of zymotic diseases in upper Thames basin and in London—Various influences asserted to effect purification of fouled water.

THE facts and theory, of which a general sketch has now been given, indicate that wherever it is the custom of a population to drink the water of rivers into which the excrements of men are discharged, such population is daily exposed to the risks of infection from typhoid and other morbid discharges, and periodically to that from cholera dejections.[1] A brief account will now be given of some investigations into outbreaks of these diseases, which in the opinion of physiologists and medical men have afforded conclusive evidence in regard to the communication of cholera and typhoid fever by means of drinking water. The facts referred to have already been published and commented on, on various occasions, and are probably perfectly well known to all who are concerned with the water supply of London; but in no paper on the subject of the water question could they well be omitted, as they are of the most vital moment in any general consideration of the matter. The evidence in each case has been described and exhaustively analyzed by men of the highest scientific reputation.[2]

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[1] Sixth Report of Rivers Pollution Commission, 1874.

London has suffered on four occasions from epidemics of cholera, which occurred in the years 1832, 1849, 1854, and 1866. In 1832 the population was 1,681,641; the water supply from shallow wells, the Thames, and the Lea was polluted, but there was no efficient system of sewerage and no rapid conveyance of excreta into the rivers. The mortality was 31·4 per 10,000 of the population. In 1849 the sewerage was completed, the use of water-closets was universal, the population had increased to 2,286,800, the excrement of the population was rapidly conveyed to the Thames, the Lea, and the Ravensbourne in that part of their course whence the drinking water of the metropolis was derived, and the mortality was 61·8 per 10,000.

In 1854 the population was 2,504,198. The water supply had somewhat improved, as a small portion was taken from above Teddington Lock and out of reach of the London sewage. The mortality was 46 per 10,000 of the population. In 1866 the population was 3,037,991. The whole of the water supply was taken from the Thames above Teddington Lock, the Lea at Lea Bridge, instead of Old Ford, and the deep chalk wells of the Kent Company. The latter were not free from pollution by the Ravensbourne water, and the East London Company occasionally used the fouled water at Old Ford, but on the whole the water had greatly improved. The mortality from cholera was only 18 per 10,000 of population. A general view of the mortality from cholera during the several epidemics, and the condition of the water supply indicated that the former varied directly with the degree of foulness of the latter. Of course such evidence is not conclusive. There might have been other causes connected with the condition of the atmosphere which might have had a determining effect on the virulence of the several epidemics. But other circumstances came to light which again connected the severity of the cholera epidemic with the condition of the water supply. Dr. W. Farr in a letter addressed to the Registrar-General in 1854 pointed out that the mortality during the epidemic of 1849 varied according to the degree of foulness of the drinking-water, which increased in proportion to the density of the population draining into it. Thus of every 10,000 people supplied from the Thames at Kew, 8 died of cholera. Of every 10,000 supplied from the river at Hammersmith, 17 died. People drinking water taken from below Chelsea Hospital died to the extent of 47 in every 10,000, while 163 in every 10,000 perished of those who drank water taken from the Thames at Battersea and between Hungerford and Waterloo bridges. Here again, however, it may be held that the deductions from such evidence are open to doubt. Density of population, as has already been noticed, tends to the creation of an infectious atmosphere, and greater density might lead to a higher rate of mortality independently of the quality of the water consumed. Still further evidence was collected, and this extended over the periods of two cholera epidemics, viz. those of 1849 and 1853-54.

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[2] Registrar-General's Return of Births, Deaths, and Marriages for quarter ending 31st December, 1854. Letter of Dr. W. Farr, F.R.S. Report of the Royal Commission on Water Supply, 1869. Evidence of Mr. John Simon, F.R.S., Medical Officer of the Privy Council. Reports on outbreak of Cholera in East London, 1866. Dr. W. Farr, F.R.S., and Dr. E. Frankland, F.R.S., to the Registrar-General. Capt. Tyler, R.E., to Board of Trade. Mr. J. Nassau Radcliffe to Privy Council. Sixth Report of Rivers Pollution Commission.

The Southwark and Vauxhall Company and the Lambeth Company supplied during the periods in question nine registration districts on the south side of the Thames, containing a population varying from 466,000 persons in 1849, to 511,000 in 1854. The customers of the two companies within the districts were intermixed, the mains of the two companies sometimes running through the same streets, the houses in which were supplied some from one company and some from the other. The customs, habits, mode of living, and sanitary conditions of the mass of customers of the one company were in the gross precisely the same as those of the customers of the other company. The one condition susceptible of variation was the water.

During the epidemic of 1848-49, the two companies pumped water from the river at Battersea; the water was of the foulest description. The mortality of the population supplied by the Lambeth Company was 125 per 10,000; that of the customers of the Southwark and Vauxhall Company, 118 per 10,000. Before the succeeding epidemic of 1853-54, the former company had changed its source of supply to Thames Ditton, where the water was comparatively pure. The latter still pumped from Battersea, where the water was fouler than before. The mortality amongst the customers of the Lambeth Company, pumping from Thames Ditton, was 37 per 10,000. The mortality amongst those of the Southwark and Vauxhall Company, pumping from Battersea, was 130 per 10,000. In fact the death-rate amongst the persons drinking the foul water was three and a half times the death-rate of those drinking the comparatively pure water. As pointed out in the original report, here was an involuntary experiment carried out on about half a million of people under circumstances which apparently eliminated all sources of error, and constituted a test of the effect of foul water in spreading cholera.

Again, in 1866, a seeming connection was traced between the cholera epidemic and the water supply of a part of London. Cholera in high development was confined to the east parts of London, within the area of one water company. This, the East London Company, supplied two waters, the one pumped from Lea Bridge, the other from Old Ford, where the Lea was peculiarly liable to contamination. The Old Ford water was only used occasionally to supplement the lesser supply. It was distributed to a portion of the company's area in the early part of July, and on the 11th July the outburst of cholera commenced. The Old Ford reservoir was in communication with a foul reach of the Lea where it was held up by locks, as a continuous gravel-bed underlay both, and choleraic discharges were known to have been poured into the river. The cholera was practically confined to the area over which the foul water was distributed.

The conclusions derived from the intense outbreak of cholera which occurred in Sept., 1854, in the neighbourhood of Broad Street, are almost too well known to need recapitulation. It may be recalled that ninety persons perished within a very limited area, and within a period of five days, and that a very careful investigation, conducted by Dr. Snow, and the results of which were for the most part confirmed by the Rev. Mr. Whitehead, showed that in all except a small percentage of cases the attacks were confined to persons who drank the water from a well in the street referred to. It was found that this well was fouled by the percolations from a cesspit which was in close proximity, and the contents of which had been infected by cholera discharges shortly before the outbreak commenced. In all investigations of this kind there are two principal facts which have to be borne in mind, as they tend to complicate the phenomena which are under observation, and lead in some cases to apparently contradictory results. The one is that the air in certain cases acts as the carrier of choleraic poison, and also of that of typhoid fever, and the other that there is in some persons an exceptionally great constitutional resistance to infection. The one fact leads to cases of cholera when infected water has not been consumed, and the other brings before the observer cases of immunity from the disease when such water has been drunk. But the activity of foul water in causing cholera, if it is exerted, will make itself visible by its preponderative effect, and the preponderance of results is in reality just as valuable as evidence of cause as if the results were all one way. That is to say, as if there were no cases except amongst those who drank suspected water, and every person who did drink such water were attacked by cholera. Reverting to the evidence collected regarding outbreaks of cholera in London, the case of Millbank Prison may be cited.[3] It suffered severely during the cholera epidemics of 1832 and 1849, when the water supply was pumped from the river outside the prison. In the midst of the epidemic of 1854, which had also invaded it, the source of supply was changed to the artesian well in Trafalgar Square. The epidemic almost immediately ceased, and during that of 1866 the prison escaped entirely.

Bethlem Hospital and the House of Occupations are two institutions in the parish of St. George's, Southwark. Since 1825 they had been supplied with water from an artesian boring. They entirely escaped cholera during the epidemics of 1832, 1849, and 1854, although the surrounding neighbourhood suffered severely.

Reports from provincial towns tell the same tale. In 1832 and 1849 Manchester and Salford drew a supply of highly polluted water from the Irwell and from shallow wells. Their mortality from cholera in the former year was 890, in the latter 1115. In 1854 and 1866 these towns used upland unpolluted water collected in reservoirs. The mortality in 1854 from cholera was 50, in 1866 it was 88.

The city of Glasgow was supplied in 1832 with polluted water from the Clyde. The mortality from the cholera was in that year 2842, or 140 per 10,000 of the population. In 1849 a portion of the water supply was obtained from a purer source at Gorbals. The mortality from cholera was 3792, or 106 per 10,000. In 1854 it was 3886, or 119 per 10,000, the water supply being as in 1849. In 1866 the town was receiving a copious and pure supply from Loch Katrine. The mortality from cholera was 68, or 1·6 per 10,000. The reduction of mortality at Paisley and

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[3] Report of Rivers Pollution Commission, 1874.

Hamilton on the introduction of the Loch Katrine supply was equally striking.

Salisbury in 1849 suffered severely from cholera. It had a polluted water supply. In 1854 a new supply from an unpolluted source was introduced to the greater portion of the town, but fifteen deaths occurred from cholera, and it was found that in every instance, without exception, they were in houses which had not been supplied with the new water. In 1866 there was an abundant supply of good water throughout the town. Only one death from cholera occurred, and that was an imported case. In August, 1866, there occurred at Margate an outbreak of virulent cholera, confined to one house, in which it killed six out of twenty inmates. It was found that they drank water from a highly polluted well. The inmates of adjoining houses who did not use the water escaped entirely. At Theydenbois in Essex the following case came under observation and investigation.

A case of choleraic diarrhœa was imported into a house, and two days afterwards a most violent outbreak of cholera commenced, which destroyed nine persons out of a household of twelve. It was found on examination of the drainage that there was a leakage from the cesspool—into which the cholera dejecta passed—into the well which furnished the supply of drinking-water. Here the sequence of cause and effect was so rapid and marked as to leave no doubt regarding the connection.

At Goodrington and Roundham, near Paignton, Chulmleigh in Devon, Chester, Doncaster, and Swansea, there were outbreaks of cholera coincidently with a polluted water supply.

It has been stated on good authority that even in Calcutta, where cholera is endemic, a remarkable decrease in the prevalence of the disease has been remarked since the introduction of a purer water supply to replace that formerly drawn from the river and tanks supplied by surface drainage.

Since 1866 there has fortunately been no opportunity in this country of pursuing these investigations into the diffusion of cholera. It has been otherwise with typhoid fever, and year by year the facts brought to light in the reports of health officers and inspectors acting under the Local Government Board have tended to strengthen the opinion that pollution of the water supply is the most potent and general cause of the disease.

The case of Millbank Prison has already been quoted as an instance of the elimination of cholera by the substitution of a pure for an impure supply of drinking water. It affords also a striking example of the influence of impure water in determining the prevalence of typhoid fever. For many years previously to 1854 the great unhealthiness of the prison had been a cause of anxiety to the authorities, and various measures were vainly resorted to for its improvement. Everything that could be thought of in the way of diet, ventilation, and drainage was tried without effect. As has already been mentioned, the source of the water supply was changed in 1854. Instead of drinking water from the river outside the prison, but filtered before use, the inmates drank that drawn from the artesian well in Trafalgar Square, and from that time typhoid fever, which had been especially fatal, practically ceased to exist. The deaths from that disease in the eighteen years from 1855 to 1872, at the old rate of mortality obtaining when the foul water was drunk, would have been 102. They were actually only two. It appears from a report addressed to the Society of Medical Officers of Health by Dr. Tidy, that the prison, since 1874, has been supplied by the Chelsea Water Company from Thames Ditton, and that the health statistics have continued to be satisfactory. This would tend to show that, as might also be inferred from other considerations, the Thames at Ditton furnishes a purer water than it does at Millbank. It does not seem to invalidate the conclusion that the foulness of the river water at the latter place was the cause of typhoid fever.

In the autumn of 1867 there occurred a violent outbreak of typhoid fever at Terling in Essex. There were 300 cases and forty-one deaths. The village was in an almost indescribable state of filth, and there was intense pollution of the wells with soakage from cesspools. The outbreak of fever coincided with the rising of water in the wells, due to rain following a drought, and involving naturally the washing in of polluting matter.

At Wicken Bonant in Essex, enteric fever appeared in the autumn of 1869. The parish well communicated with a brook running through the village. There were forty-five cases and four deaths. Forty-two cases occurred amongst persons drinking water from the parish well, and only one case amongst those, 118 in number, who drank water from private wells. The source of the water supply to two persons was doubtful. The first case in the village occurred in a cottage close to the brook channel and above the parish well, and the privy of which was on the edge of the brook. The dejections of this person were thrown into the privy, and thence reached the brook, and the parish well eventually participated in the pollution.

[4] In 1879 there was an outbreak of typhoid fever at Caterham, which resulted in 352 cases and twenty-one deaths. The epidemic commenced on the 19th of January, and up to the 20th of February it was confined to persons who drank the water supplied by the Caterham Waterworks Company, of whom 334 were attacked. Subsequently other cases occurred, apparently due to secondary infection. The circumstances of the outbreak were investigated by a sanitary inspector, under the orders of the Local Government Board. It was finally discovered that a workman, suffering from typhoid fever accompanied by severe diarrhœa, had, on the 5th of January, and for some days subsequently, worked in an adit leading from the company's well, and that the well had without doubt been fouled with some portion of his discharges.

The above account refers to a few typical epidemics of enteric fever which have been subjected to investigation, and many others might be mentioned. There seems to be the strongest possible evidence in support of the assumption that water polluted with animal matters, and especially with human excrement, may become poisonous; and that specific diseases, such as cholera and typhoid fever, may be diffused amongst persons who drink water polluted with a very minute quantity of the discharges of persons suffering from such diseases.[5] The evidence as to the mode of diffusion of other zymotic diseases is not so clear; but there is some reason for believing that summer diarrhœa is connected with the high temperature of the water supply. We have here, however, a large basis of fact on which to establish practical measures of water supply. Health statistics[6] indicate that in the course of every year 58,000 persons suffer from zymotic disease within the area of the Thames and Lea basin above the intakes of the water companies, and contribute poisonous discharges to the sewage or to the soil; that there are within the metropolis annually nearly 20,000 cases of enteric fever, and 66,000 cases of diarrhœa, of which latter 4600 are fatal.

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[4] Ninth Report of Local Government Board.

Dr. Hunter, who was commissioned by the Government to investigate the history of the outbreak of cholera in Egypt in 1883, has stated it as his opinion that the disease has established itself endemically in that country; and if this be the case, it lends additional seriousness to the question of the pollution of the source of the water supply of London, for it would imply that within a fortnight's journey by steamer a perpetual hot-bed of cholera exists.[7] Those who endeavour to vindicate the quality of the water supply tell us to rely on the efforts of the conservancy boards in excluding from the rivers sewage and other pollution; on the purification of sewage by irrigation, by intermittent filtration and chemical treatment; on the self-purifying power of flowing water; and on the efforts of the water companies to improve the water they pump up by subsidence reservoirs and filtration through sand and gravel. It is necessary, therefore, to examine the scientific evidence adduced on the subject of the value and efficacy of the various purifying processes enumerated, and to ascertain how far the official reports of the conservancy boards and other information support the view that conservancy has been successful in excluding polluting matter from the rivers under their control. The results of the various processes for purifying sewage can only be tested by chemical analysis of the effluent liquid after the sewage has been dealt with, and of the water of the rivers into which the liquid passes; and a brief sketch of the nature of the analyses usually carried out, and the meaning to be attached to the information they convey, will be given in the next chapter.

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[5] A recent inquiry into an outbreak of scarlet fever at Fallowfield, near Manchester, has afforded evidence that milk may become infected with the special poison of this disease, and be the means of communicating the affection to persons drinking the milk with an incubative period of only thirty-six hours. The circumstances point to a process of self-multiplication of some organism in the milk subsequently to its introduction. Diphtheria also has been communicated by milk. See Twelfth Report of Local Government Board for Medical Officer's Report.

[6] Reports of the Registrar General of Births, Deaths, and Marriages.

[7] This statement has been emphasized by the outbreak of cholera in the South of France, which occurred after it was written.

# CHAPTER IV.

## NATURE OF CHEMICAL ANALYSIS OF WATER AND VALUATION OF INDICATIONS.

Chemical analysis of potable water—Difficulties—Various processes adopted—Combustion process—Permanganate process—Albumenoid ammonia process—Dr. Cory's estimate of the relative merits of each process—Nature of analysis carried out by Chemical Analyst to Local Government Board—Objects in view and indications conveyed by analysis—Temperature—Total solid matter—Organic carbon—Organic nitrogen—Ammonia—Nitrogen as nitrates and nitrites—Total combined nitrogen—Chlorine—Total hardness—Suspended matters—Delicacy of manipulations necessary—Quantities of soluble impurities ordinarily dealt with—Chemical results, considered alone, may lead to fallacious conclusions—Necessity of considering previous history of water—Chemical analysis no test of presence of specific poisons communicating disease—Instance of purposely polluted sample of water—Great value of chemical analysis properly understood.

It is most important that in considering the question of the condition of the water supply of the metropolis, a clear and accurate conception should be formed of the practical value which attaches to the analyses of the various waters by chemists on behalf of the Local Government Board and the water companies.[1] It must be borne in mind that the analysis of water is one of the most difficult of chemical processes. No method has yet been devised by which the amount of organic matter in water can be even approximately determined. This difficulty arises from the instability of such compounds, their mixture in the water with mineral matters, their constant tendency to degrade into mineral compounds, especially when exposed to the action of chemical re-agents, and the minute quantity in which the individual organic matters are present in any manageable bulk of water.

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[1] See Sixth Report of the Rivers Pollution Commission, 1874. Annual Report of the Medical Officer to the Local Government Board for 1881. Analysis of potable water by Dr. Frankland, F.R.S., and H. E. Armstrong, Esq., Journal of Chemical Society, vol. xxi.

Chemists are not in agreement as to the merits of the various known processes for the analysis of potable water. Four methods appear to be in vogue in this country; viz. the combustion process of Messrs. Frankland and Armstrong, that of Dr. Dupré, the permangranate test of Forchammer, and the albumenoid ammonia process of Messrs. Wanklyn, Chapman, and Smith. The first, as described by its inventors, consists in,—

1. The estimation of the total solid constituents.
2. The estimation of the carbon and nitrogen contained in the organic portion of the solid constituents.
3. Estimation of the nitrogen in the form of nitrates and nitrites.
4. Estimation of ammonia.

The special feature in the process consists in the combustion of the solid residue in a glass tube from which the air has been exhausted, after eliminating from the water combined and dissolved carbonic acid, and from the solid residue the nitrogen existing as nitrites and nitrates, so that all carbon evolved as a product of combustion must necessarily have formed part of the organic matter present in the water. And after the deduction of all nitrogen contained in the water as ammonia, the balance of the nitrogen obtained by combustion must also have been a constituent of the organic matter.

The products collected are: carbonic acid, nitric oxide, and nitrogen. The subsequent separation and determination of these is easy, the measurement of the volume of each gas, combined with a knowledge of the temperature and atmospheric pressure, as shown by thermometer and barometer, affording the data for the determination of the weights. It has been stated that by this means the one-millionth part of a gramme (·000001) of nitrogen and five-billionth parts of a gramme (·0000005) of carbon are distinctly measurable quantities. It must, however, be borne in mind that there are always inevitable errors due to manipulation, want of perfect purity in re-agents, reading of results, and so on, which must be taken into consideration when looking at analyses put forward. It would appear that when very minute amounts of impurities are dealt with these errors may result in a possible maximum deviation from truth of about 25 per cent. in ordinary samples of London water, even in the most skilful hands. Under such circumstances, of course, the error is of minor importance.

In Dr. Dupré's modification of the combustion process, the carbon is determined separately from the nitrogen, and the latter, brought into contact with a stream of hydrogen gas as it is evolved in the combustion tube, issues as a constituent of ammonia, and is collected in an absorption apparatus containing hydrochloric acid.

The permanganate test depends on the oxydizing action of potassic permanganate. When a few drops of the permanganate are added to water containing organic substances and acidulated with sulphuric or hydrochloric acid, the permanganate yields oxygen to the organic substance, and the violet colour disappears. By testing the water with a permanganate solution of known strength, it is possible to ascertain how much oxygen the matters in solution in the water are capable of abstracting, and hence, it is assumed, to arrive at a quantitative appreciation of the amount of organic matter.

The albumenoid process is founded upon the remarkable change which albumen and some other organic substances undergo during prolonged ebullition with an alkaline solution of potassic permanganate, by which their nitrogen is converted into ammonia. It is asserted by Professor Wanklyn that the albumenoid ammonia formed, although it does not represent the whole of the nitrogen in the organic matter, has a constant ratio to it.

In the annual report of the medical officer of the Local Government Board for 1881, Dr. Cory furnishes a statement of the results of the analysis of purposely polluted water by each of the above methods. These analyses were carried out by Drs. Frankland and Dupré, and Professor Wanklyn. Dr. Cory derives from the experiments a high opinion of Dr. Frankland's process for the determination of organic carbon, and nitrogen, and of Dr. Dupré's process for the determination of organic nitrogen.

As respects the permanganate or Forchammer process, he observes that it is not satisfactory. Applied to the examination of water polluted with different amounts of polluting matter, it does indeed tell the direction of the difference, and even gives some indications of the relative amounts; but even for this it is important that the circumstances of the several samples shall have been identical, and one not kept longer than the other. The test affords no indication of the total amount of oxydizable matter in the water, and cannot therefore be employed in comparing water from different sources. Dr. Frankland has pointed out that some organic substances are apparently very imperfectly oxydized by the permanganate, and that some mineral substances, notably nitrites, so often present in water, decolorize the permanganate more rapidly than organic substances. Apparently this process affords very imperfect indications of the quality of water.

Of the albumenoid ammonia process, Dr. Cory remarks that it may be trusted to show which of two samples of water is the most polluted, when the polluting material contained in each is of the same kind. Also in that case, and when the absolute amount of polluting material is not great, it is capable of determining the relative degree of pollution in a number of samples. But when the polluting material is in large absolute quantities, a given difference in the extent of pollution is not indicated by a corresponding difference in the yield of albumenoid ammonia. He further states that equal amounts of albumenoid ammonia may be furnished by extremely different quantities of nitrogenous polluting material; and, conversely, extremely different quantities of albumenoid ammonia may be furnished by the same quantity of polluting material. Dr. Frankland's experiments indicate that there is no constant ratio between the amount of albumenoid ammonia and the nitrogen present in the matter under analysis.

Monthly reports of analyses of the metropolitan water supply are furnished by several eminent chemists: viz. by Dr. Frankland to the Local Government Board, by Drs. Bernays and Tidy for the water companies to the official water examiner, and by Professor Wanklyn and W. J. Cooper to the Local Government Board. Of these reports, however, that by Dr. Frankland is the only official one—that is to say, it is the only one made at the request of a department of her Majesty's Government, Dr. Frankland being specially appointed by the Local Government Board to make monthly analyses of the water supplied to London.

The following tabular statement shows the average results of analysis as applied to the waters of the Thames and the Lea, and to those waters as supplied to consumers by the companies after filtration, and also to the well water from the chalk. An analysis of average sewage is added for the purpose of comparison.

IN PARTS PER 100,000.

| Description. | Total Solid Matters. | Organic Carbon. | Organic Nitrogen. | Ammonia. | Nitrogen as Nitrates and Nitrites. | Total combined Nitrogen. | Chlorine. | Hardness. |
|---|---|---|---|---|---|---|---|---|
| Thames at Hampton . . | 32·13 | ·285 | ·061 | ·012 | ·232 | ·304 | 1·53 | 21·91 |
| Lea at the intake of the East London Water Company | 36·90 | ·242 | ·057 | ·015 | ·384 | ·453 | 1·95 | 26·9 |
| Water supplied to London from Thames . . | 28·11 | ·174 | ·031 | ... | ·207 | ·233 | 1·5 | 19· |
| ,, Lea . . . | 29·30 | ·127 | ·023 | ... | ·252 | ·275 | 1·6 | 20·6 |
| ,, Wells in chalk . | 32·10 | ·060 | ·018 | ·017 | ·322 | ·353 | 2·3 | 19·2 |
| Average sewage . . . | 72·2 | 4·696 | 2·205 | 6 703 | ·003 | 7·728 | 10·66 | ... |

To convert the above into grains per gallon, multiply by 7 and move the decimal point one place to the left.

It will probably suffice, as an elucidation of the objects of analysis, if we consider the table of the results of the chemical analysis as it appears in the monthly report of Dr. Frankland to the Local Government Board, heading by heading. These are (1) temperature, (2) total solid matter, (3) organic carbon, (4) organic nitrogen, (5) ammonia, (6) nitrogen as nitrates and nitrites, (7) total combined nitrogen, (8) chlorine, (9) total hardness. The results in the table are expressed in parts per 100,000.

1. *Temperature.*—Uniform lowness of temperature is a quality which adds to the value of water for dietetic purposes. Warmth favours the growth and increase of animal and vegetable life in water, and renders it objectionable from a physiological point of view. The temperature of the Thames water, as supplied by the companies varies from 46° Fahr. in winter to 70·3° Fahr. in summer. It is much inferior in this respect to the water from the wells of the Kent and the springs of the Coln Valley Companies; the average temperature of which is 56° Fahr., and the range throughout the year 4° Fahr.

2. *Total solid matter.*—The solid matter represents the total mineral and organic impurities present after filtration in 100,000 units of water, and left on evaporation. It must be understood that the term "impurities" is used in a strictly chemical and not a popular sense. Some of the impurities so called, which are of a mineral character, may conduce to the palatability of the water. There is no such thing in nature as chemically pure water.

Rain water, from the moment of its formation, and even while passing through the atmosphere, commences to collect foreign matters, and its constituents vary frequently as it passes over the surface of the earth, or through various strata. The mineral constituents, in the quantities in which they are present in ordinary water, are perfectly innocuous; but those which confer hardness, if present in large quantities, render water unfit for some uses. The organic matters may or may not be innocuous; and the chemist, while he can separate and weigh certain constituents of this organic matter, has no means whatever of informing us whether or not the water containing such matter can be drunk with impunity. The quality which creates the danger confers no chemical particularity on matter which has yet been discovered.

3. *Organic carbon.*—By the determination of the quantity of carbon which exists in a given quantity of water as a constituent of organic matter, the chemist obtains a very rough measurement of the total amount of organic matter. The greater the quantity of organic carbon present the greater in general the quantity of other organic matter. Carbon is, in a chemical sense, the skeleton of organized beings, and the weight of the aggregate of carbon atoms is in some sort a measure of the weight of the oxygen, hydrogen, and nitrogen which clothed the atoms and formed the organic structure which the analyst has broken up. The presence of organic carbon implies that the water has been contaminated with matter of vegetable or animal origin; but considered alone, it affords no information regarding the source of pollution. The smaller the quantity of organic matter the better *cæteris paribus* will be the water. An amount of carbon, exceeding 0·2 parts in 100,000 of water or ·14 grains per gallon, will, if the carbon is derived from vegetable matter, render the water unpalatable. If from animal sources, the same effect does not follow, but the pollution is, of course, in that case a source of danger. The rule is laid down in the Sixth Report of the Rivers Pollution Commission, that if the organic matter in the water has been derived, even partially, from animal sources, the organic carbon should not exceed 0·1 part in 100,000 of water.

4. *Organic nitrogen.*—The proportion of nitrogen to carbon in any given specimen of water gives in most cases a clue to the nature of the pollution, whether animal or vegetable. The smaller the quantity of organic nitrogen the less likely it is that the water contains organic matter derived from animals. It is the last which is especially dangerous. It is supposed that organic matters act injuriously because they have a great tendency to putrefy; and because, while in that condition, they either form unorganized poisons, or, in putrefying, allow of the multiplication of organisms of a low type, which act as poisons when introduced into the

body. Nitrogenous substances are infinitely more liable to undergo putrefaction than organic bodies, in which nitrogen is absent; and the opinion is general that the deleterious character of water is proportional to the quantity of organic nitrogen which it contains. Pollution by animal matters of human beings involves the risk of infection of the water with the poison of specific diseases.

5. *Ammonia.*—Water usually derives ammonia from decomposing animal matter, but some may be collected from the atmosphere. River water rarely contains more than ·01 part per 100,000, or one part per 10,000,000 parts of water. In unpolluted water it is still less. Its importance as a result of analysis rests on its usual connection with animal pollution.

6. *Nitrogen as nitrates and nitrites.*—In the presence of oxygen the nitrogen of the animal organic matter present in water is for the most part transformed into nitric and nitrous acid, and this, combining with the basic earths or alkalies present in the water, forms nitrates and nitrites. This change takes place in water, but much more rapidly if the water is passing through porous earth.[2] The presence of nitrates and nitrites in water is therefore an indication of previous sewage or animal pollution. The salts are themselves innocuous; but if organic matter is also present in the water, its ancient origin is indicated, since it most probably represents the undecomposed residue of the quantity originally present.

7. *Total combined nitrogen.*—Nitrogen exists in the water as a constituent of organic matter, of ammonia, and of the nitrates and nitrites of the basic substances present in it. A minute quantity of nitrogen, amounting to about ·032 part in 100,000 parts of water, may generally be attributed to the ammonia,

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[2] It has been discovered that this nitrification of the animal azotized matters is connected with the presence of minute organized bodies which seem to play the part of a ferment.

and nitric or nitrous acid usually present in minute quantities in the atmosphere, and which is washed out by the rain as it falls.

The remainder sums up, as it were, the past and present pollution of the water by nitrogenous organic matter of either animal or vegetable origin, so far as exhibited by the water at the time of analysis. The past pollution, in so far as it is derived from nitrates, nitrites, and ammonia, which represent old organic matter reduced to an innocuous mineral condition, and present pollution in so far as it is derived from matter still present in an organic form. But nitrogen received into water in combination with organic polluting matter disappears to a certain extent as part of the food of animal and vegetable organisms growing in the water. It is also dissipated by the effect of putrefaction in the absence of atmospheric air; but in the presence of nitrates or nitrites. The organic matter in putrefying withdraws oxygen from the nitrates, and liberates nitrogen, which is only partially converted into ammonia; the remainder escapes. The total combined nitrogen found in a sample of water is therefore not a measure of the whole pollution sustained.

The tendency, it will be seen, of animal or vegetable matters dissolved in water is to pass into mineral compounds. This change takes place ultimately in rivers and lakes, but much more rapidly in the pores of an open soil. When the oxidation is complete their carbon is converted into carbonic acid, their hydrogen into water, their nitrogen partly into ammonia, but chiefly into nitric and nitrous acid, which, combined with bases, such as lime, magnesia, and soda, usually present in the water and forming salts, remain as such a long time dissolved in it. The mineral compounds are innocuous.

8. *Chlorine.*—The chlorine found in potable water is always combined with other elements, and generally exists as a constituent of common salt. The liquid excrements of animals

contain chlorine in large proportion. Human urine, 500 parts of chlorine, or 800 parts of common salt in 100,000 parts. Unpolluted upland water rarely contains more than one part of chlorine in 100,000 parts. Its presence in considerable proportions in water exposed to pollution may be taken as favouring the assumption that liquid excrement has entered the water; but as there are various other sources whence large quantities may be derived, its presence in quantity, in the absence of collateral evidence against a water, should not suffice to condemn it.

9. *Total hardness.*—The quality of hardness is given to water by certain mineral substances, the chief of which are the salts of lime and magnesia. There is no reliable evidence tending to show that hard water is in any way deleterious when used for drinking; but hardness has an objectionable effect in cooking, washing, and in many manufacturing processes. It also leads to dangerous incrustations in boilers. The salts referred to decompose soap, and form curdy and insoluble compounds containing the fatty acids of the soap and the lime and magnesia of the salts. It is only after the lime and magnesia salts have all been decomposed at the expense of the soap that the latter begins to produce a useful effect. The scale of hardness adopted in the monthly reports of the chemical examiner to the Local Government Board is based on the assumption that one part of carbonate of lime, or its equivalent in other salts in 100,000 parts of the water, constitutes one degree of hardness. Clarke's scale represents one grain of carbonate of lime to the gallon as one degree of hardness. The aggregate waste of soaps in washing in a large community supplied with hard water represents a very considerable pecuniary loss; and if to this be added the waste in manufacturing processes, not only of soap, but carbonate of soda, dyes, &c., caused by hardness, the importance of securing, if possible, a supply of soft water becomes evident. Hardness due to carbonate of lime can be got rid of in considerable measure

by boiling, and almost entirely by the addition of a solution of caustic lime to the water (Clarke's process). Hardness caused by sulphate of lime or magnesia cannot be removed economically. The former is distinguished as temporary hardness, the latter as permanent hardness. In the table under notice both kinds of hardness are grouped together.

In addition to matters in solution, natural water has usually present in it suspended mineral and organic matter. The greater part of such substances is removal by filtration; but minute particles of clay are only got rid of with extreme difficulty; and as regards organic matter, it is known that certain portions pass through all filters. The mineral suspended matter is innocuous. The organic matter is deleterious equally with organic matter in solution. It favours animal and vegetable growth, and is liable to putrefy. If organisms causing specific diseases are present in water, they must obviously be included in the suspended and not in the dissolved organic matter. All suspended mineral and organic matter left after filtration will form part of the "total solid matter" noted in the second column of the table of analytical results above referred to. Even after the most efficient filtration, river water is still full of excessively minute particles of suspended matter, as may be seen by causing a beam of sunlight or electric light to pass through it in a darkened room.

The delicacy of the chemical manipulations which are necessary in order to avoid damaging error in the results of water analysis, may be conceived if we consider the proportions borne by the impurities in any given bulk of water to such bulk.

Taking examples from amongst a number which have been reported, viz. (*a*) water from the drainage basin of Ullswater Lake in Cumberland, (*b*) average Thames water as supplied by the companies, (*c*) water from deep chalk wells belonging to the Kent Company, we have the following results in parts per 100,000 :—

| | (*a*) | (*b*) | (*c*) |
|---|---|---|---|
| Total solid impurity . . . . | 3·32 | 20·40 | 30·422 |
| Organic carbon . . . . . | 0·193 | 0·141 | 0·054 |
| Organic nitrogen . . . . | 0·007 | 0·026 | 0·011 |
| Ammonia . . . . . . | 0·001 | 0 | 0 |
| Nitrogen as nitrates and nitrites . | 0 006 | 0·141 | 0·320 |
| Total combined nitrogen . . . | 0·014 | 0·167 | 0·331 |
| Chlorine . . . . . . | 0·489 | 1·08 | 1·68 |

In considering, for instance, the important quality of water indicated by the quantity of organic nitrogen contained, the chemist is dealing with pollution, represented in such samples as those above by seven parts in 100,000,000, or a few thousandth parts of a grain per gallon, and the largest amount in which any element is present little exceeds three-tenths of a grain per gallon. Moreover, there is no possibility of deriving with any degree of certainty correct inferences regarding the suitability of the water for dietetic purposes from the analytical facts alone. The organic carbon of the Cumberland water exceeds the amount of the organic carbon in the better qualities of Thames and Lea water delivered in London, but the chemical significance of this fact, as indicating greater pollution of the former, is overridden by the knowledge obtained from an examination of the sources of supply, that the carbon of the Cumberland water is derived mainly from peat, which is innocuous, while that of the Thames is the result, in a great measure, of animal and sewage pollution, which is liable from time to time to become poisonous. The proportion of organic nitrogen is certainly a guide in the estimation of the quality of the impurities, but it is not an infallible test. During the oxidation of vegetable matters, the nitrogen tends to assume a greater ratio to the carbon, because the latter oxidizes more quickly. During the oxidation of animal matter the contrary is the case; so that vegetable matter tends to assume the chemical character of animal matter, and animal matter that of vegetable matter.

The water from the deep chalk wells of the Kent Company (analysis *c*) shows a far larger total of combined nitrogen than the filtered water of the Thames, but the consideration that the former must have percolated through hundreds of feet of chalk before reaching the wells is held to revindicate the quality of the water, as such filtration, prolonged probably for many months, is a security for the removal of any noxious qualities which the water might originally have possessed.

It is more particularly when we bear in mind the facts connected with the diffusion of disease by means of water, that the fallibility of the revelations of the analyst, if taken alone, becomes evident. The dangerous pollution represented by 3½ grains of the discharge from a patient suffering from enteric fever in a gallon of water, has been found on experiment to present itself to the analyst in the shape of the one-thousandth part of a grain of albumenoid ammonia, having no characteristic whatever to distinguish it from albumenoid ammonia derived from healthy animal matter.[1] The accidental pollution of the well at Caterham by a workman suffering from enteric fever was diluted with 1,800,000 gallons of water, which were pumped into pipes extending for some miles, and yet this pollution, which would have been utterly without significance to an analyst, sufficed to infect 334 persons who drank the water with the same disease.

Nothing but a careful study of the history of a water, combined with that of the results of analysis, can enable us to form an opinion of its suitability for domestic use. It must be traced from its first appearance in springs or wells, and its surroundings with reference to the question of pollution must be examined throughout its course until it reaches the consumer. The analytical chemist is in a position to warn us of possible danger, for he can detect pollution of a water with organic matter, and he can generally adduce evidence, more or less reliable, regarding the nature of the pollution, whether animal or vegetable, or even whether solid or liquid excremental matters. His general knowledge of the composition of the unpolluted water of a district will guide him in detecting sewage contamination in other samples from the same district. He can never be in a position to assure us of absolute safety in the use of any water, because the most poisonous qualities may exist in a form which chemical analysis cannot detect, and, indeed, in water which by the test of mere organic impurity would be highly approved. The lesson taught us by the investigations of pathologists and chemists, carried out during the past thirty-five years, is that water polluted by organic manner, especially by organic matter of animal origin, and most of all by excremental matter from human beings, possesses at times a poisonous quality, which has not as yet revealed itself by any particulate chemical property to the analyst, or by any particulate appearance to the microscopist, but only by its pathological and deadly effects on populations. Common sense warns us therefore to avoid water polluted in any degree by town sewage and drainage from cess-pools, middens, tan yards, manured fields, or other collections of filth incidental to aggregations of human beings.

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[1] Eleventh Report of Local Government Board. Report by Dr. R. Cory on the results of an examination of water purposely polluted.

It is by no means intended to imply that analysis is of no value as an aid in forming an opinion of the quality of a water, and its suitability for potable purposes. On the contrary, it is as respects the mineral character of the water a reliable guide, and as regards the organic matters its indications are most valuable, either as suggesting the necessity for an inspection of the surroundings of a source of water supply, or as confirming the results of such inspection.

In the case of the rivers which supply the metropolis with water, it is known that the impurities incidental to a large population enter them, and analyses of the water have the direct significance due to the fact that the presence of the $\frac{1}{80}$ part of a grain of organic carbon per gallon may mean the presence of ordinary sewage to the extent of 1 per cent. of the bulk of the river water, and so in proportion. For a mixture of one gallon of sewage with ninety-nine gallons of pure water would yield on analysis that amount of organic carbon per gallon, and although we must admit the effect of decayed vegetation in contributing sometimes to the quantity of this element, we are always confronted with a potential of danger, due to the possible presence of the whole quantity of sewage indicated.

# CHAPTER V.

## SEWAGE DEFECATION.

Defecation of sewage a vexed question—Theoretical value of London sewage—Financial results of defecation of sewage generally unsatisfactory—Methods of defecation in use—Broad irrigation—General theory of process—Most favourable conditions for sewage irrigation—Quantities per acre of sewage to be used—Crops—Sewage carriers—Irrigation the best mode of filtration—Conditions to be attended to—Effluents never sufficiently pure to enter into source of domestic water supply—Causes militating against financial success of sewage irrigation—Results of prize competition of sewage farms under auspices of Royal Agricultural Society, 1879—Intermittent downward filtration—Depends on oxidizing property of air occluded in soils—Economizes space—Quantity of sewage per acre—Reason for intermittence of filtration—Action of various soils different—Disadvantages compared with broad irrigation—Works usually unfitted to deal with rain discharge—Artificial filtration no security against poisonous effects of polluted water—Chemical processes for sewage treatment—Chemical principle on which they depend—Usual effects produced—Purification not effective—Investigations by Rivers Commission—Results confirmed—Lime process—A B C process—Valuable constituents in sewage effluents—Experiments with A B C process in 1870—Market value of solid product—Various other chemical processes—All the processes have some value—Table of results of experiments of Rivers Commission—Chemical processes cannot render sewage fit for discharge into rivers used to supply water for domestic use.

THE effectual, and at the same time economical defecation of sewage has for many years been a vexed question with sanitary engineers and chemists, and it has not yet been satisfactorily solved. Theoretically, sewage is a product of considerable agricultural value. The market value of the fertilizing constituents of the sewage of London discharged into the river in one year is no less than 1,000,000 sterling. Yet none of the processes for the utilization of sewage can be considered generally successful in a financial point of view; on the contrary, in by far the greater number of cases where they have been adopted by local authorities they are worked at an annual loss to the ratepayers often of considerable amounts.

There are three recognized methods of purifying sewage:—

1. Broad irrigation.
2. Intermittent downward filtration.
3. Chemical precipitation.

In broad irrigation the sewage is directed on to the land in such a manner that it flows in thin sheets over it, and gradually sinks into and percolates through it. In its passage it is brought intimately into contact with the air present in the pores of the soil, and the organic matter is for the most part oxidized and converted into innocuous mineral compounds. The inorganic matter is also assimilated by the crops which are grown. Finally, the effluent liquid, divested of the greater portion of the organic matter which it contained in solution, and the whole of the suspended matter, issues into the water-courses by means of the drainage outlets of the subsoil provided either naturally or artificially. Sometimes, and notably in the summer, the whole ot the sewage is absorbed by the soil, and does not visibly revert to the drainage system. In such case a considerable portion of the water gradually evaporates, and the impurities transformed as already described are left in the soil. The above is a description of irrigation perfectly conducted, but in many instances in practice an excessive quantity of sewage is delivered over the land, and a considerable proportion escapes over the surface and enters the water courses without having been effectually filtered. The result is a foul effluent. In some cases sewage will gravitate to the outlet, and be at a sufficient elevation to flow over the selected land. This, of course, represents a favourable condition in sewage farming. In other cases it is necessary to pump the sewage to a sufficient height to give it the necessary command of the ground. The best land for sewage irrigation will have a free loamy soil and open subsoil, the surface tolerably even, with southern aspect and gentle slopes. Clay land will require deep draining. Dressings with sewage must be at even and regular intervals. The flooding of the land with large quantities amounting to from 8000 to 10,000 tons per annum to the acre is wasteful, and in wet weather leads to imperfect depuration. The best general results will probably be obtained with a distribution of from 500 to 2000 tons per acre per annum, if carefully applied with due regard to the soil, the crops, and the weather, but an acre can be made to dispose successfully of as much as 5000 tons per annum (which is equivalent, on the average, to the sewage of 100 persons) so far as defecation is concerned, and sometimes more. Italian rye grass is considered to be the most suitable crop, alternated, however, every third year with roots, and then another course of rye grass. Crops of grass aggregating in the year fifty to sixty tons to the acre are obtained. Ensilage will probably now be resorted to for the purpose of storing the crop, and avoiding a glut in the summer market for green food. In some places market gardening has been found to offer an opportunity for the profitable use of sewage.

Sewage irrigation works must be simple in character. Sometimes chemical precipitation of the suspended matter has been carried out as a preliminary to irrigation, but this is unnecessary. The straining off of the coarser matter, such as sticks, rags, &c., is all that is desirable. Application of the liquid must be made by surface carriers, and the sewage should be dealt with in a fresh condition, before putrefaction has set in. Ridges and furrows will require levelling; main carriers must be laid nearly level, so as to command the area below. If over eighteen inches in diameter they should probably be constructed of brick; eighteen inches and under of earthenware pipes or concrete. They should be provided where necessary with outlets and simple sluice-boards. Minor carriers may be formed of agricultural tiles, but jointed and laid three-parts in soil, so that one tile can be taken out to allow surface overflow. All ordinary conduits can be open trenches made by hand or plough. Contour gutters may be run, and when irrigation of the land below is desired they can be blocked up with a spade or turf, so as to cause them to overflow at the edges. They can be ploughed up when cultivation requires it, and made afresh when required.

Irrigation is filtration of the best kind combined with utilization of the sewage. It implies separation of the water from the filth in it, and the transformation of that filth into innocuous mineral compounds. Considered as a mechanical and chemical agent, an extent of porous soil used in irrigation, with periodical intervals of rest, is the best possible strainer, oxidizer, and filter of water like the sewer water of towns. The area of the land required for the satisfactory disposal of a given quantity of sewage varies with the nature of the soil, the drainage, the season, and the nature of the crop grown. In the winter, when vegetation is checked, the evaporation slow, the rainfall large, and the soil more or less saturated, the difficulties attending sewage irrigation are of course increased. The ground is then wet and not well adapted to receive the liquid which nevertheless must be dealt with, and the period of repose of each section after a flooding should be larger than in the summer, when the conditions are reversed. Not more than $\frac{1}{20}$ of the whole area of a sewage farm should be under sewage at the same time. The condition for the most successful defecation of the sewage is that it should filter through the soil and pass out of it by subsoil drainage, and not merely run over the surface and so into the water-courses, or pass through cracks and fissures into the subsoil drains. Without careful and continued attention the end in view will not be fully attained, and it is certain that at times on every sewage farm the effluent from one cause or another is more or less foul. When the system of sewerage of a town is such that storm water enters the sewers, the effluent sewage cannot be dealt with by irrigation. All defecation is for the time being suspended. Whatever be the character of the effluent from an irrigation farm, as revealed by chemical analysis, and however nearly it may approach the composition of the purest water, it can never be certain that it is in a condition to be safely passed into a source of domestic water supply.

The causes which have militated against the financial success of sewage-irrigated farms have chiefly been the exorbitant rents demanded for land proposed to be used for this purpose, or the high prices paid for its purchase; the fact that as towns generally occupy valleys, the sewage has often to be pumped up by steam power to a higher level, in order to obtain a sufficient command of the ground, which must be free from the risk of being flooded, and should have the necessary slope to cause the sewage to travel over it; the prejudice which exists, in many instances, against sewage-grown produce; the difficulties sometimes experienced in the summer in disposing of the heavy green crops which deteriorate, if kept after being cut; the occasionally excessive dilution of the sewage by subsoil water which enters the drains, and increases the cost of pumping and distribution; mismanagement, due to want of experience, in what is a very special kind of farming, which has led to the selection of unsuitable sites; the waste of capital in elaborate and costly preparation of the ground, and the waste of labour in directing the details of daily operations.

The subjoined tabular statement, taken from the report of the judges appointed to adjudicate in the sewage farm prize competition, carried out under the auspices of the Agricultural Society in 1879, gives the financial results and other particulars in the case of nine sewage farms.

The general conclusion was, that under favourable conditions, sewage farms will show a fair profit. The proper way in which to regard sewage farming is that it supersedes and is an alternative to scavengering, which would have to be paid for, if sewers were not provided to carry away the filth of towns. Therefore, even if the operations are carried out at a loss, it does not necessarily follow that the ratepayers have reason to complain. It is, of course, assumed that it is the duty of a community to

## EAR 1878-79.

| Name Tow |  | Population contributing to sewers. | Number of people contributing to an acre, calculated on whole area of farm. | Number of people contributing to an acre, calculated on area actually irrigated. | Remarks. |
|---|---|---|---|---|---|
| Aldershot | d. | 8,000 | 77 | 81 | Information not available. |
| Bedford | 7¼ | 18,690 | 102 | 122 | Includes cost of pumping sewage. |
| Birmingha |  | 112,500 | 444 | 539 | No rent charges for freehold land. |
| Croydon | 1¾ | 55,000 | 121 | 172 |  |
| Doncaster | 1½ | 21,000 | 69 | 92 | Does not include cost of pumping. |
| Guisborou |  | 5,300 | 219 | 330 |  |
| Leamingt |  | 23,000 | 30 | 142 | Rent includes amount paid for sewage, but does not include cost of pumping. |
| Reading | 1 | 33,000 | 51 | 433 | Does not include cost of pumping or rent. |
| Wrexham |  | 10,000 | 96 | 99 |  |

[*To face page* 56.

dispose of its refuse in such a manner as to prevent its being harmful to its neighbours, and that this condition is not fulfilled by sending sewage into a river to be carried by the current to towns lower down the stream. The natural desire of the Metropolitan Board of Works to make a profit out of London sewage for the benefit of the ratepayers has led them to impose conditions on persons desiring to utilize it, which have militated against all projects for that purpose, and the pollution of the lower reaches of the Thames is becoming a formidable evil.

In intermittent downward filtration purification of the sewage depends, as in broad irrigation, on the oxidizing power of the air permeating the pores of the soil, but a far larger quantity of sewage is applied to a given surface of land, and in order to carry away the percolating fluid the land must be artificially drained at a depth of four to six feet below the surface. It is estimated that in practice a land filter properly prepared on suitable soil will defecate sewage to the extent of about 25,000 tons per acre per annum, which represents, on the average, the product of 500 persons in a fully water-closeted town.[1] The flow of sewage should be intermitted by dividing the land into plots, and applying the sewage to each in succession. It is necessary that there should be distinct intervals in the application of the sewage, in order that fresh supplies of air may follow the sewage in its course through the soil, and remain there in readiness for the next supply. The action of soils and their power of purifying sewage filtering through them varies considerably. In some soils nitrification takes place rapidly, in others nitrification is hardly perceptible, but the soil absorbs a large amount of the fertilizing ingredients of the sewage, but in both cases the effluent is comparatively pure. Laboratory experiments, on various soils, carried out by the Rivers Pollution Commission, indicate that one cubic yard of soil will defecate from 5·6 to 9·9 gallons of sewage per twenty-four hours, and that the cause of variation depends more on the physical condition than on the chemical composition of the soil.

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[1] In some favourable sites this has been largely exceeded.

In the process of intermittent downward filtration the fertilizing ingredients of the sewage are wasted, and probably in course of time the collection of fæcal matter in the soil would create a nuisance. It is desirable to combine chemical precipitation with filtration, and to make the latter a sequel to the former process. In power of abstracting from sewage the dissolved organic matter, intermittent filtration is on a par with broad irrigation. If rain water is admitted into the sewers, works for intermittent filtration will periodically be overwhelmed with a discharge with which they cannot cope, and the sewage must then necessarily be turned directly into the watercourses. Neither will any amount of filtration which can be artificially carried out be a security against the presence in the effluent of the poisons which, whether organized or unorganized, are known to exist at times in excremental matter.

A very large number of processes for the chemical treatment of sewage have been brought forward, but most of them are out of favour, experience having shown their inefficacy. They all depend on the property possessed by lime, iron and alumina of entering into mechanical combination with organic matter. Chemical analysis has proved that while most of the processes cause the rapid precipitation of the suspended matter, they leave the greater part of the dissolved organic carbon and nearly the whole of the dissolved organic nitrogen in the effluent liquid. The suspended matters in average sewage may be be taken as amounting to 1 lb per ton of sewage, and in general the effluent discharged after the sewage has been chemically treated takes away with it nearly 4-5ths of the putrescible matter in a state of solution, and 7-8ths of the valuable constituents.

The chemical processes for the treatment of sewage were carefully examined by the Rivers Pollution Commissioners in 1870, and they carried out exhaustive experiments in regard to the A.B.C. process which, with the lime process, was, and has, up till now, been the process most extensively used. Their conclusions were to the effect already stated, and these were confirmed by the committee appointed by the Local Government Board in 1876 to inquire into the modes of treating town sewage. The manipulation in all these processes is almost precisely the same, and a description of the *modus operandi* in the cases above mentioned may be considered to represent generally the details in all cases.

In the lime process a certain proportion of milk of lime is mixed with the sewage as it arrives at the works. The mixture is violently agitated by machinery on its way to subsidence reservoirs, where there is a large deposit of highly putrescible mud. The deposit is subsequently collected and dried.

The A.B.C. process consists in adding to sewage of the ordinary kind about 4 lbs. per 1000 gallons of the following mixture:—

| | | | |
|---|---|---|---|
| Alum | 600 parts. | Animal Charcoal | 15 parts. |
| Blood | 1 „ | Burnt Clay | 25 „ |
| Clay | 1900 „ | Chloride of Sodium | 10 „ |
| Magnesia | 5 „ | Vegetable Charcoal | 20 „ |
| Manganate of Potash | 10 „ | Magnesian Limestone | 2 „ |

The sewage is thoroughly mixed with the compound, and allowed to flow into settling tanks. The supernatant liquid is drawn off as soon as the precipitation of the suspended matters is completed. It is usually clear, but, as already observed, it contains the larger proportion of the putrescible and valuable constituents.

The valuable constituents of sewage are chiefly the different forms of combined nitrogen and phosphoric acid. The money value of these constituents dissolved in 100 tons of average sewage is about fifteen shillings, while the suspended matters contain only about two shillings' worth of them.

The results of the treatment of sewage by the A.B.C. process are exemplified by the following experiment, carried out by the Rivers Pollution Commissioners in 1870:—

2,523,520 lbs. of sewage were treated in eight and a half hours, the sewage contained 1262 lbs. of suspended matter, equivalent to one cwt. for every 100 tons of sewage. Of this, five-sixths or 1052 lbs. were ultimately retained in the tanks. 1215 lbs. of the soluble ingredients of the A.B.C. mixture were added equivalent to 925 lbs. when dried at 100° centigrade. Of insoluble matters, 619 lbs., equivalent to 501 lbs., when dried were also added, so that the total A.B.C. mixture added in due proportions weighed 1834 lbs. at the temperature of the air, or 1426 lbs. when dried at 100° centigrade.

In 2,523,520 lbs. of the effluent after treatment, there was an increase of dissolved matters of 225 lbs.; consequently it may be assumed that of the soluble matters added, 276 lbs. were precipitated. The manure produced was,—

| | lbs. |
|---|---|
| Suspended matters in sewage . . . . . | 1052 |
| Insoluble matters added . . . . . . | 925 |
| Soluble matters added and precipitated . . | 276 |
| | 2253 |

The manure as sold contains 2·76 per cent. of water, and therefore the market weight of 2253 lbs. of dried manure would be 2435 lbs. The theoretical value at 32*s.* per ton was 1*l.* 14*s.* 9*d.* The value was made out on the assumption that the market value of ammonia was 56*l.*, soluble phosphates 15*l.*, neutral phosphate, 5*l.*, and alkaline salts 1*l.* per ton, and the quantity of each of these substances in the manure produced was determined by analysis as under,—

| | Per cent. |
|---|---|
| Combined Nitrogen . . . . . . | 1·695 |
| Equal to Ammonia . . . . . . | 2·05 |
| Phosphoric acid equal to soluble phosphate of lime . . . . . . . . | 3·26 |

The actual market value of the manure is not equal to one-third of the theoretical value. A calculation of the value of the ingredients added, showed that it required chemicals costing 1*l.* 18*s.* 5*d.*, to produce manure valued at 1*l.* 14*s.* 9*d.* To this must, of course, be added the cost of labour, fuel, depreciation and interest on capital.

Of other processes may be mentioned Bird's, involving admixture of the sewage with crude sulphate of Alumina, and subsequent filtration through coke. Again, treatment with lime and chloride of iron has been tried with filtration through calcined iron ore.

Hadden's process consists in the mixture of sewage with sulphate of iron, and lime, and coal dust, thus conferring permanent hardness on the water into which the effluent is discharged. Hanson's provides for treatment of the sewage with lime and alkali waste. It cannot by any means be said that these processes are absolutely useless. As already stated, they do purify the sewage to a certain extent, and as a preliminary to intermittent downward filtration they are decidedly useful; but they invariably leave in the effluent a large proportion of putrescible matter, and in no case do they produce an effluent fit to be turned into a stream.

A summary of the conclusions of the Rivers Pollution Commissioners, regarding the results of the various methods of purifying sewage, is shown in the following table:—

*Results of Irrigation, Downward intermittent filtration, and Chemical Processes.*

| Name of Process. | Average percentage of dissolved organic pollution removed. | | Average percentage of suspended organic pollution removed. |
|---|---|---|---|
| | Organic Carbon. | Organic Nitrogen. | |
| *Irrigation.* | | | |
| Best result . . . . . | 91·8 | 97·4 | 100 |
| Worst „ . . . . . | 42·7 | 44·1 | 84·9 |
| Average „ . . . . . | 68·6 | 81·7 | 97·7 |
| *Downward intermittent filtration.* | | | |
| Best result . . . . . | 88·5 | 97·5 | 100 |
| Worst „ . . . . . | 32·8 | 43·7 | 100 |
| Average „ . . . . . | 72·8 | 87·6 | 100 |
| *Chemical Processes.* | | | |
| Best result . . . . . | 50·1 | 65·8 | 100 |
| Worst „ . . . . . | 3·4 | 0 | 59·6 |
| Average „ . . . . . | 28·4 | 36·6 | 89·8 |

No changes of any importance have been made of late years in the chemical treatment of sewage, and as chemical and mechanical reactions under the same conditions remain invariable no improvement in the results can be expected.

When the question in discussion is the fitness of the effluents for introduction into rivers forming sources of domestic water supply, it is the worst and not the average results which should be looked at, and this again does not touch the question of the danger from subtle poisons which at times exist in sewage, and which no known processes of sewage purification can eliminate.

## CHAPTER VI.

### CONSERVANCY OF THE THAMES AND THE LEA—ITS RESULTS.

Pollution of rivers otherwise than by sewage—Transfer of excreta and refuse by rain and floods—Report by Rivers Commission on the condition of the Thames and the Lea—The Thames Conservancy Board—Constitution of Board—Powers of Board—Duties—Accounts and receipts—Sale of water to companies—Results of Conservancy in purifying the Thames—Increase of pollution of the river indicated by analysis—Defects of the Conservancy Act—Annual reports of Board no index to real condition of the river—Dr. Percy Frankland on Thames pollution—Enormous expense of works for defecation of sewage—Results of notices given by Board to discontinue pollution of river—The Lea Conservancy Board—Number of Conservators—Mode of election—Tenure of office—Powers—Sale of water to companies—Conservancy Board powerless to deal with many sources of pollution—legal difficulties—Dr. Frankland's report on Lea shows increased pollution—Admitted by the Sanitary Engineer to Board—General deduction to be drawn as to results of Conservancy.

THE processes which have been described in outline in the preceding chapter represent the sum of the resources of the sanitary engineer for the defecation of sewage. They are, of course, only applicable in the case of towns, large or small, which are provided with a system of water-closets and sewers, and do not touch the case of places—whether coming under the category of towns, or that of villages and hamlets, or isolated houses and farms—which collect excremental matter in cess-pools and middens, and distribute liquid matters and other refuse daily over the surface of the ground. These matters go through processes of putrefaction and oxidation; but in the case of solid substances, decay and resolution into inorganic substances is slow.

Thus the ground in the vicinity of habitations, under the condition described, becomes polluted. Fortunately for the inhabitants, the surface is periodically washed by rain, and large quantities of organic matter, soluble or insoluble, are carried by every gutter, rill, or rivulet, into the larger water-courses, and thence into the streams and rivers which drain the country. This transfer of polluting matter into rivers is also carried out in a wholesale manner when heavy rain or floods wash the manure, sometimes consisting of the contents of cesspools, from fields near the water-courses or river margins. It results that the amount of organic matter found in rivers is invariably proportional to the density of the population in their basins.

In the case of the Thames and the Lea a million and a quarter of people inhabit the river basins above the intakes of the water companies which supply London. Within that area, there are about the same number of four-footed beasts, consisting of cattle, horses, sheep, and pigs. The major portion of the inhabitants are congregated either on the banks of the rivers or their tributaries, or at least within a short distance of the streams. The first Rivers Pollution Commission, in their Report dated 1866, gave the following description of the condition of the river Thames at that time:—" Taking," they state, " the effect of this immense animal population in detail, we find everywhere water-closets almost at the outset of every rivulet, privies washing into it, farmyards draining into it, live stock fouling it at drinking places, woollen factories, paper-mills and tan-yards discharging their liquid refuse into it, drainage from ploughed lands to which manures have been applied running into it, garden and house waste running into it, all within a very few miles of its origin. Thereafter, some miles lower down, it may be pumped to reservoirs to supply the drinking water of a town, and thence through chamber utensils, sculleries, and water-closets, it finds its way through sewers to the river channel, once more uniting with streams which may have been abused in a similar, but in a different, possibly in a less degree, it forms the River Thames, which grows in volume not only by the accession of different affluents, but during certain portions of its course, and notably between Wallingford and Reading, by the mixture of pure spring water rising in enormous volumes in its bed, until it reaches the intake of the metropolitan water companies, and is distributed for the domestic use of the inhabitants of the metropolis." Eight years later, viz. in 1874, the Second Rivers Pollution Commission reported, as the result of their inspection of the river, that the pollution recorded in 1866 was not only unabated, but intensified.

In 1867 the First Rivers Pollution Commission described the River Lea as being in a frightfully polluted condition, and stated that masses of excrement accumulated in pools in the river until sent down by the periodical freshets. The Second Rivers Pollution Commission, in 1874, reported that no amelioration had taken place since 1866 in the condition of the Lea.

Two public bodies are entrusted with the duty of cleansing the rivers in question and preventing their pollution: these are the Thames and Lea Conservancy Boards.

[1] The former was constituted by Act 20, 21 Vict. c. 147, which Act was amended in 1864 by Act 27 and 28 Vict. c. 113. Under that Act the number of conservators was fixed at eighteen, as follows:—The Lord Mayor, ex officio, two aldermen and four members of the Common Council, the Deputy-Master of Trinity House, two members nominated by the Lord High Admiral, one by the Privy Council, and one by Trinity House; six members to be elected as follows: two by registered shipowners, two by owners of lighters and steam-tugs employed on the river, one by the owners of river steamers, and one by dock owners and wharfingers. Members are subject to re-election every five years. By the Thames Navigation Act of 1866, 29 and 30 Vict. c. 89, the powers of the Conservancy Board

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[1] Firth's "Municipal London."

were, as already stated in Chapter I., enlarged. The conservancy of the Thames and Isis, from Staines to Cricklade, was vested in conservators, of whom the conservators of the lower navigation formed the majority. Four new conservators were added in supersession of the commissioners who previously controlled the upper Thames under an old Act of 1795, and one was appointed by the Board of Trade.

The duties of the conservators include the issuing of notices directing persons to discontinue to pollute the river by sewage, mud, refuse of manufactures, or in any other manner; the prosecution of offenders against the Act; the dredging and improvement of the river bed and banks; the laying down of mooring stations, raising of wrecks, repair and construction of locks and weirs. Four additional conservators were elected at Oxford in 1866 under the 7th and 8th Sections of the last Act. The receipts from the lower part of the river, which include tonnage dues, tolls, pier dues, and payments by water and canal companies, as also the expenditure, are kept separate from those of the upper navigation. The principal receipts in respect of the latter are the contributions of the water companies, amounting in 1882 to 12,050*l.* The jurisdiction of the Board has been extended to points on the tributaries of the Thames district ten miles in a direct line from the main stream. The efforts of the Conservancy Board for the abatement or prevention of pollution of the river have been strenuous and unintermitted; but the results of analysis show that the measures taken have had no practical effect in reducing the amount of the organic matter present in the water. The report of Dr. Frankland on the London water supply for the year 1883 proves this conclusively. Taking the mean amount of organic impurity in the Thames water, as supplied by the companies during 1868, at 1000, the mean impurity in the several succeeding years is represented by the following figures :—

| | | | |
|---|---|---|---|
| 1868 | 1000 | 1876 | 903 |
| 1869 | 1016 | 1877 | 907 |
| 1870 | 795 | 1878 | 1056 |
| 1871 | 928 | 1879 | 1175 |
| 1872 | 1243 | 1880 | 1263 |
| 1873 | 917 | 1881 | 993 |
| 1874 | 933 | 1882 | 1033 |
| 1875 | 1030 | 1883 | 850 |

It is also pointed out by Dr. Frankland that since 1868 the provision of subsidence reservoirs by the water companies has been considerably increased, and the filtering arrangements improved, so that the figures above given would indicate a considerably increased impurity of the river water before treatment.

In fact, as the foulness of the river invariably increases when it is in flood, the average amount of organic matter present during any year appears to depend on the extent to which the deposited impurities are washed into it by rain.

The failure of river conservancy, in so far as it is directed to the object of preserving the water from contamination, was inevitable, because the legislature has not conferred on the Board the power so to control the use of the river and its tributaries and the ground adjoining by the population as to prevent the entry of refuse and excremental matters day by day and directly or indirectly, and legislation of a sufficiently drastic character to achieve this end would be intolerable and impossible. The conservators have endeavoured to prevent the entry of raw, i.e. undefecated, sewage into the river or its tributaries within the limits of their jurisdiction, and to exercise a control over the operations for treating sewage so far as to secure the most satisfactory effluent from sewage irrigation and other works which present knowledge can produce. In this part of their work they have been hampered by the unfortunate wording of the Act under which they take their powers, and by the difficulty met with by local authorities in disposing of their sewage, except at enormous expense. In order to secure a conviction against any person or local authority conveying sewage or offensive matter into a channel or stream communicating with the Thames, the prosecutors must be in a position to prove[2] that the sewage, &c., will be carried, or be likely to be carried, through or out of the channel or stream and into the Thames; and as there are not wanting chemists who assert, though apparently without any satisfactory proof, that sewage, with whatever noxious matter it may contain, is destroyed after travelling a short distance in a running stream, the judicial decisions in recent prosecutions under the Conservancy Act have been disastrous to the moderate results which had been achieved.[3]

In their annual reports of the results of their administration the conservators content themselves with repeating that the river is now practically free from sewage. But in a paper read before a meeting of the Society of Arts in March, 1884, Dr. Percy Frankland showed that out of twenty-two towns in the upper Thames basin, containing 5000 inhabitants and upwards, with an aggregate population of 269,221 persons, six towns, containing in the aggregate 72,628, still discharged sewage effluents in the Thames, or into water-courses connected with it, without any attempt at previous purification; and it has been pointed out in the last chapter that while effluents from chemical works for sewage treatment are invariably foul, even those from irrigated fields or issuing from land filters cannot be depended on. This will be the more apparent when it is considered, that while on the one hand the effectiveness of all these processes depends on constant care and attention, and on the thoroughness with which they are carried out, on the other it is the interest of the local authorities to look to economy more than anything else, regardless of the quality of the effluent which affects their neighbours below them in the drainage system, and not themselves. Indeed, the local authorities can hardly be blamed if they show a tendency to shrink from the expenditure which the so-called defecation of sewage entails. At Oxford the sewage works cost 185,810*l.*, at Abingdon 23,000*l.*, at Wallingford 19,000*l.*, at Reading 205,000*l.*, at Henley 22,000*l.*, at Windsor 45,000*l.*, at Windsor Castle 14,000*l.*, while the estimated cost for Staines, a town of 5000 inhabitants, is 32,000*l.* It is to be regretted that the reports of the Thames Conservancy Board contain no detailed information regarding the progress made in the interception of pollution gravitating towards the Thames and its tributaries. On two occasions additional information seems to have been called for by the House of Commons, in the shape of returns showing the results of notices issued under the Act of 1866, calling upon local authorities and other persons to discontinue the transmission of sewage and offensive matters into the streams. This is information which might well accompany every annual report. The last return of the kind referred to, made to an order of the House of Commons, is dated the 9th of July, 1880. From this it would appear that, as respects the Thames and its tributaries, 167 notices had been issued. In fifty-three cases the notices had been attended to, and the sewage had been dealt with satisfactorily; in two cases the notices had expired, and further reports were awaited. In three cases legal proceedings were in progress for non-compliance with the notices. In 107 cases the notices had not expired. In two cases the sewage had been diverted, but the character of the effluent was not satisfactory.

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[2] Thames Navigation Act, 1866, Section 63, Clauses 3 and 4.

[3] 1884. B. Lee Conservancy *v.* Hertford Corporation. Thames Conservancy *v.* Uxbridge Local Board of Health.

The Lea Conservancy Board was constituted in 1868 under Act 31 and 32 Vict. c. 154, for the purpose of superintending the purification of the River Lea, and also improving the locks and weirs, and adapting the river to purposes of navigation. The conservators are thirteen in number. Five of them are appointed by the trustees, who were superseded in 1868, acting in conjunction with the riparian land-owners. Of the remaining eight conservators two are nominated by the New River Company, one by the Corporation of London, one by the Metropolitan Board of Works, one by the barge owners on the river, and one by the head officers of the various local authorities on the banks of the river. The tenure of office is limited to[4] four years, but the members are eligible for re-election. The Board have power to purchase all the various riparian rights detrimental to the purity of the water, for the compulsory purchase of land for improving the navigation, and for the purification and cleansing of the river, and prevention of pollution. The drainage of Luton is admissible into the river, but only after undergoing such purification as the Secretary of State shall from time to time prescribe. Hertford, Tottenham, West Ham, and other adjoining towns are placed under similar restrictions. The water companies drawing water from the river pay certain annual sums, which are not to exceed 1500*l.* in the aggregate. Revenue is also derived from water rentals and tolls. In the case of the River Lea, as in that of the Thames, the Conservancy Board is powerless to deal with the entry therein of an immense amount of polluting matter created by the large population on the banks of the river and its tributaries. They have no doubt with commendable zeal enforced expenditure on the part of a number of towns with a view to the purification of their sewage by irrigation or chemical treatment; but they, as well as the conservators of the Thames, have met with legal difficulties in enforcing obedience to the Act, and they have recently been worsted in an action brought by them against the Corporation of Hertford for sending a foul effluent from their chemical purification works into the Lea. In a number of other cases the results of the attempted defecation are admittedly still unsatisfactory. A number of private nuisances have been abated by the strenuous exertions of the officers of the Conservancy Board, but the impression appears to be gaining ground that it is hopeless to suppose that any practical administrative measures can save the river from grave pollution. Dr. Frankland's report on the London water supply for 1883 gives the following figures, showing the relative state of pollution of the Lea in a series of years from 1868 as under :—

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[4] Act of 1874.

Thames, 1868 . . . . 1000.

| | | | |
|---|---|---|---|
| 1868 | 484 | 1876 | 562 |
| 1869 | 618 | 1877 | 596 |
| 1870 | 550 | 1878 | 747 |
| 1871 | 640 | 1879 | 947 |
| 1872 | 819 | 1880 | 1013 |
| 1873 | 693 | 1881 | 765 |
| 1874 | 583 | 1882 | 711 |
| 1875 | 751 | 1883 | 620 |

The state of pollution of the Lea in 1868, represented by the figures 484, was described by the Rivers Pollution Commission in the most alarming and forcible language. In 1883, notwithstanding all the exertions of the Conservancy Board for fifteen years, in dealing with notorious sources of contamination, the pollution was represented by the figures 620, an increase of 28 per cent.

But perhaps the strongest evidence as to the hopeless condition of the Lea is afforded by the fact that the sanitary engineer to the Conservancy Board, in a pamphlet dated the 24th of January, 1882, which is the joint production of himself—Sir Joseph Bazalgette, C.B.—and Messrs. Law and Chatterton, adopts the view to which the following extract gives expression :—

"Notwithstanding the laudable efforts which the two water companies who derive the main portion of their supply from the River Lea have made, and the large sums which they have expended in the construction of storage reservoirs and filter beds, and, further, notwithstanding the means which have been adopted by the towns and villages situated in the Lea valley for the purification of their sewage, the fact remains, that the water, as delivered to the consumers, instead of improving in purity, has deteriorated to such an extent since the year 1868, in which the Lea Conservancy Act came into operation, that in 1880 the amount of organic impurity had increased, according to Dr.

Frankland, 136 per cent." After pointing out the danger to public health which this implies, the pamphlet goes on to recommend a system of intercepting sewers as a remedy for the evil.

It seems to be an inevitable deduction from the facts which reveal themselves, that the Thames and the Lea are seriously polluted with excremental matter and refuse of all descriptions, and that such pollution, with all its possible evil consequences to the health of the inhabitants of the metropolis who are supplied with water from these sources, is unavoidable.

# CHAPTER VII.

## NATURAL AND ARTIFICIAL PURIFICATION OF RIVER WATER.

The fact of the pollution of the Thames generally admitted—Reliance on processes of purification—Dissolution of oxygen in water—Apparent abstraction of oxygen by nitrogenous matter in flowing water—Experiments in Thames—Evidence given before Water Supply Commission of 1869—Report of Commission on this subject—Experiments of Rivers Commission detailed in Sixth Report—Analyses of water of rivers Irwell, Mersey, and Darwen—Laboratory experiment—Results arrived at—Opinion of Commissioners—Evidence given before Royal Commission on metropolitan sewage discharge, 1884, and conclusions of Commissioners—Difficulty of investigations—Recent experiments of Dr. Percy Frankland on the water of the Upper Thames—Natural processes of purification afford no guarantee of safety—Artificial processes of purification—Storage reservoirs and their uses—Filtration.

A CONSIDERATION of the physical condition of the valleys in which the Thames and its tributaries flow, as well as ocular demonstration, so conclusively prove that these streams must necessarily receive a considerable amount of polluting matter, of animal as well as vegetable origin, that those who contend that the Thames and the Lea are suitable sources of water supply admit the fact. But while doing so, they assert that processes of purification, natural and artificial, render the water innocuous before it reaches the consumer. The natural process on which dependence is placed, consists in the oxidation of the organic matters in the running water, and their assimilation by aquatic plants and animal life. The artificial processes are the subsidence of impurities in storage reservoirs, in which the water is impounded, and filtration through artificially prepared masses of sand and gravel.

Water dissolves a certain portion of both the constituents of air, but a larger proportion of oxygen on account of the greater solubility of that gas. River water in its normal condition contains about 1 of oxygen to 2 of nitrogen by volume.

In 1859, when the River Thames, between bridges, was highly offensive, Professor Miller ascertained the amount of free oxygen at various points of its course, the results being as shown below :—

| Place where sample was taken. | Oxygen in a litre of water. | Proportion of oxygen to nitrogen. |
|---|---|---|
| | Cubic cent. | |
| Kingston | 7·4 | 1 : 2 |
| Hammersmith | 4·1 | 1 : 3·7 |
| Somerset House | 1·5 | 1 : 10·5 |
| Greenwich | 0·25 | 1 : 60 |
| Woolwich | 0·25 | 1 : 52 |
| Erith | 1·8 | 1 : 8·1 |

From this it appears that at Kingston the water, as regards dissolved oxygen and nitrogen, was in a normal condition, and that the amount of free oxygen fell rapidly as the river became more and more polluted, and commenced to rise again as the estuary was approached and the sewage became more diluted. Hence it was inferred that the dissolved oxygen played an active part in the oxidation of the sewage, and, as it was constantly subject to renewal by the contact of the water with the air, that this action was considerable.[1]

The question of the so-called self-purification of river water was examined by the Royal Commission on Water Supply of 1869, and they found that the evidence given by scientific witnesses on the subject was most conflicting. Dr. Lyon Playfair, Mr. Simon, Medical Officer to the Privy Council, and

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[1] Dr. Frankland is of opinion that the action referred to is mainly due to sulphuretted hydrogen, which is generated in large quantities by the putrescent mud in the bed of the river. This gas very rapidly removes dissolved oxygen from water.

Dr. Parkes, Professor of Hygiene in the Army Medical School at Netely, while laying great stress on the formidable danger created by the pollution of domestic water by sewage or refuse animal matter, declined to admit that the alleged self-purification of water by oxidation, &c., could be relied on to render such water safe. On the contrary, they were of opinion that the action was slow and uncertain, and that water containing internal evidence of pollution should be condemned. Mr. Wanklyn, Professor of Chemistry at the London Institution, gave evidence as to the persistency of organic compounds, which he designates albumenoid matter, and stated that the changes which took place in the organic matter were both slow and irregular. Sir Benjamin Brodie, Professor of Chemistry at the University of Oxford, dilated on the imprudence of using water into which sewage had entered, because it was impossible to tell whether or not at any given time what was noxious had been destroyed. Dr. Simon said it should be made an absolute condition for a public water supply, that it should be incontaminable with sewage, for the principle that the sewage becomes innocuous in water after a time is not a safe one to adopt as the basis of sanitary regulation.

Dr. Frankland, Professor of Chemistry at the Royal Institution, gave similar evidence, and while admitting the great improvement effected in sewage water used for irrigation, he asserted that there was no practical process by which water which had once been contaminated with sewage could again be rendered fit for human use. On the other hand, Drs. Letheby and Odling stated that sewage water used for irrigation could be safely discharged into any running stream, and they appeared to hold the opinion that the natural process of purification going on in running water was so effective and rapid that it could be relied on to render river water, such as that of the Thames, innocuous. The former went so far as to assert as a conclusion which he had arrived at from observation and experiment, that if sewage containing nearly 100 grains of solid matter per gallon, out of which probably fourteen or fifteen grains were organic, is mixed with twenty times its bulk of the ordinary river water, and flows a dozen miles or so, there is not a particle of sewage to be discovered by any chemical process. The latter, however, assigned a limit to this, and considered it possible that the river might become so polluted as to be dangerous. On this subject the Commissioners in their report remarked as follows :—

"The only point raised against the Thames water on the ground of organic contamination is of a less positive character. It is said that water which has once been contaminated with sewage may still contain undecomposed organic matter, which, though inappreciable by the most delicate chemical tests, may still exercise prejudicial effects on the human system. The strongest form of this objection has reference to some opinions now prevalent, that certain forms of disease, such as cholera and typhoid fever, are propagated by germs contained in excremental matter, and it is conceived possible that when matter of this kind once gets into streams, these germs may escape destruction and long preserve their dangerous character. It is said that no process is known by which such noxious matter can be removed from water, and therefore it is argued that water which has at any time been contaminated by sewage is thenceforth unsuitable for domestic use. We cannot admit these opinions as sufficiently well established to form any conclusive argument for abandoning an otherwise unobjectionable source of water supply."

The Rivers Pollution Commission, in view of this report, instituted a series of careful experiments, with the object of throwing light upon the important point referred to; and in their report, dated 30th June, 1874, they give an account of the results. They dealt with sections of the Irwell, the Mersey, and the Darwen, within which these rivers received no additional pollution, and compared analyses of samples of water taken at the head and tail of each section. For the Mersey there was a section thirteen miles in length from Stretford Road Bridge to its junction with the Irwell; in the case of the Irwell, a length of eleven miles from Throstlenest Weir to its junction with the Mersey; and in the case of the Darwen, a section of thirteen miles from its junction with the Blackwater to its junction with the Ribble. After making necessary corrections for dilution by unpolluted affluents, the following results were exhibited :—

| Description of samples. | Reduction in 100,000 parts of water. | | Percentage reduction of organic elements. | |
|---|---|---|---|---|
| | Organic carbon. | Organic nitrogen. | Organic carbon. | Organic nitrogen. |
| Irwell after flow of 11 miles at temperature of 6° 2′ to 6° 8′ C. | ·095 | .. | 4·5 | .. |
| Irwell after flow of 11 miles at temperature of 12° 2′ to 13° 3′ C. | .. | ·028 | .. | 11·8 |
| Irwell after flow of 11 miles at temperature of 17° 8′ C. | ·632 | .. | 29·6 | .. |
| Mersey after flow of 13 miles at temperature of 4° 3′ to 4° 8′ C. | ·150 | ·017 | 20·8 | 17·9 |
| Darwen after flow of 13 miles at temperature of 6° 8′ to 10° 7′ C. | .. | ·039 | .. | 13·2 |

It is evident that various sources of error must always operate in such experiments. The entry of unpolluted water is not at once followed by its uniform dissemination throughout the polluted stream. The two streams may flow for some distance side by side. Again, the sample of water obtained at the tail of the section is not necessarily a portion of the same body of water of which a sample was taken at the head of the section. Still, whatever may be said on this point, it is certain that, unless scientific assertions are based on experiments, they are of very little value. The result of those abstracted above, and of others made in the Thames, showed that the reduction in the proportion of organic matter by a flow of some miles was exceedingly small.

In order to eliminate the sources of error present in dealing with rivers, a laboratory experiment was carried out by mixing one volume of London sewage with nine volumes of water. The mixture was well agitated, and freely exposed to air and light every day, by being syphoned in a slender stream from one vessel to another, falling three feet through the air. In this case the mixture was more thoroughly brought into contact with the air than happens in a river, the upper surface only of which is exposed. The mixture contained, when the experiment began, in 100,000 parts, ·267 of organic carbon, and ·081 of organic nitrogen. After ninety-six hours it contained in 100,000 parts ·250 part of organic carbon, and ·058 organic nitrogen. After 192 hours ·2 parts of organic carbon, and ·054 organic nitrogen. Assuming that the effect was approximately equivalent to that produced by the flow of river water containing 10 per cent. of sewage for 96 and 192 miles, at the rate of one mile per hour, the reduction effect was as follows :—

| | Percentage Reduction. | |
|---|---|---|
| | Organic carbon. | Organic nitrogen. |
| In flow of ninety-six miles at rate of one mile per hour . . . . . . | 6·4 | 28·4 |
| In flow of 192 miles at rate of one mile per hour . . . . . . . | 25·1 | 33·3 |

It was found, by other experiments carefully conducted, that sewage matters in water abstracted the uncombined oxygen but slowly. Thames filtered water, mixed with five per cent. of sewage, contained immediately after mixture ·946 part by weight of oxygen in 100,000 parts. The mixture kept in a stoppered bottle for 168 hours had still left in it ·04 of the original quantity of oxygen, and calculation showed that, if freely exposed to the air for six days, only 62·3 per cent. of the sewage would have been oxidized. It is impossible not to recognize the fact that these experiments, and others which are detailed in the most precise manner by the Commissioners, justify them in their assertion that there is no river in the United Kingdom long enough to secure the oxidation and destruction of any sewage which may be discharged into it, even at its source.

The question of the oxidation of organic matter in flowing water has recently been exhaustively argued before the Royal Commission on Metropolitan Sewage Discharge, with reference to the particular case of the sewage passing into the river at Barking Creek and Crossness. According to the Commissioners, the evidence proved that there is a progressively increasing impurity of the river from Teddington downwards to the outfalls, and then a decreasing impurity down to Gravesend, below which place the sewage is not perceptible. The oxygen dissolved in the water exhibits a corresponding decrease where the impurity increases. They consider that this shows that the oxygen does active work in oxidizing, and thus purifying the sewage impurities in the river. They continue as follows :—"Besides the purification of the river by oxidation, there is evidence of its purification by means of animal and vegetable life. Animals of a low type, notably entomostraca (such as water fleas), feed upon the solid elements of sewage. These animals themselves excrete solid matters, but of course in a diminished amount; the balance is decidedly in favour of purification.

"Minute algæ and other plants of low organization vegetate in the polluted reaches, and, by giving off oxygen, they tend to promote the purification of the water.

"The nett result of these complex processes—pollution by sewage, oxidation of the sewage, consumption by minute animals, and reoxygenation of the river by the action of vegetable life, and by renewed absorption of oxygen from the air—is, that in cold weather and in cool, wet summers, the pollution of the river exists indeed, but does not increase, the above processes being adequate to prevent that. But during hot, dry weather, the pollution increases, exceeding the purifying power of the agents for its removal, and the river then becomes a nuisance, more or less great, and within greater or less limits."

There was on this occasion, as usual, the most conflicting evidence on the part of the scientific witnesses. The chemists called on behalf of the respondents, viz. the Metropolitan Board of Works, who pollute the river, all testified to the efficiency of the purification effected by the oxidizing action; while those called for the complainants, viz. the Corporation of London, as Port sanitary authority, the Thames Conservancy Board, and others, gave evidence showing the insufficiency or inefficacy of the natural process of purification, the presence of sewage at Chiswick and Hammersmith, probably derived from the Barking outfall, and the probability of the existence of a nuisance from the conditions exhibited by analysis.

As the general result of the examination of a very large number of credible witnesses, the Commissioners express an opinion that the existence of a nuisance, caused by the discharge of sewage at Barking, under certain conditions, has been satisfactorily proved, and that this extends for a certain varying distance above and below the outfalls. It is admitted on all sides that there are two causes only which limit the extension of the nuisance in either direction, viz. dilution, and the natural processes of purification, which the Commissioners describe. It is on the question of the degree of importance to be assigned to the last, that there is a conflict of opinions amongst chemists and other scientific men. As to the facts of the enormous dilution of the sewage, there can be no doubt. The average daily discharge of the Thames at Kingston is 217 million cubic feet, and this is supplemented by the land drainage between Kingston and Southend. The water passing up at Erith during a single flood-tide contains 3200 million cubic feet. It is true that the oscillations of the tidal ebb and flow result in the retention of the same body of water for a considerable time within the lower reaches, so that in fact the motion of the sewage is composed of a series of oscillations, in which, however, those towards the sea preponderate on account of the downward flow of the land water, and it is the fact that the flood water at Erith is largely composed, not of fresh sea water, but of that which has already been mixed with sewage. Still the influx of sea water from the estuary at each flood-tide must be considerable, and there is the absolute discharge into the sea yearly of a quantity of upland water eight times greater than the quantity of sewage discharged during the same period. It seems clear that the mere process of dilution of the sewage would account for its practical disappearance, so far as chemical tests are concerned, at a moderate distance from the outfalls; and considering the difficulty imported into the analytical investigations by the presence of sea water which always contains matter more highly nitrogenous than sewage, as well as organic carbon, it would seem to be impossible to derive from the facts connected with the condition of the lower Thames any information regarding the degree of rapidity of the oxidation of the sewage or its purification by other natural actions, which would be useful or throw any fresh light on the persistence of sewage or other polluting matter in the fresh water of the upper part of the river, which is used for drinking.

Recent experiments carried out by Dr. Percy Frankland on the water of the Thames between Oxford and London, of which an account is given in a paper read by him before the Society of Arts in March, 1884, show that there is a gradual increase in the pollution by organic matter of the river from Oxford to Hampton. This effect takes place, notwithstanding the entry into the river, where it flows through chalk, of enormous quantities of pure spring water rising through the bed. It is a significant fact, and its importance is not affected by the acknowledged difficulty which exists in the application of the results of such analyses to the determination of the effect of the travel of any given particle of organic matter in flowing water in inducing the oxidation of such matter, and which has been noticed in the case of the experiments on the River Irwell. In its broad aspect this fact supplies evidence in direct contradiction to the theory that natural processes of purification will eliminate organic matter at such a rate as to overtake the tendency to accumulation due to the contributory effect of affluents and to the increased density of the population on the banks of the main stream as the metropolis is approached. Water is added to the main stream as it flows on and receives the natural drainage, but polluting matter is added at a greater rate, and oxidation fails to restore the balance.

But even if it were satisfactorily proved that the dissolved oxygen plays a very active part in the destruction of the nitrogenous compounds forming the putrefactive part of ordinary sewage or animal matter, it would not affect the question of the possible survival for a protracted period in water of the poisons which are from time to time present or generated in excremental or putrefying matter. That micro-organisms, which appear to produce disease, have sometimes extraordinary vitality, has been shown by repeated experiments. As an instance may be mentioned that of Dr. Klein, recorded in the Eleventh Report of the Local Government Board, in which he boiled the spores of the deadly bacillus of splenic fever and subsequently exposed them in a mixture of ice and salt to a temperature of 36° below freezing point, on Fahrenheit scale, and yet found that they retained in full vigour their power of self-multiplication in a suitable medium.

If we quit the subtilties of scientific disputation and regard the question of the alleged self-purification of flowing water in its relation to the quality of a water supply derived from rivers in the condition of the Thames and the Lea, from the point of view of practical men, we shall have little hesitation in arriving at the conclusion that the natural processes of dissolution of organic matter are utterly insufficient to afford any reasonable guarantee of safety in the use of such water.

Two processes are resorted to by the water companies for the purification of the river water prior to its distribution to the inhabitants of London. These are storage and filtration. Storage consists in the impounding of the water in open reservoirs, where it is kept sometimes for a number of days before it is turned on to the filters. The use of these reservoirs is twofold: in the first place, a company which possesses a considerable area of reservoir is enabled to cease taking in water from the river for a time, while still keeping up the supply to the filters, service reservoirs, and mains. In the second place, the water while standing deposits a considerable portion of the matter, which, while in motion in the river, is held in suspension. The faculty of intermittent abstraction is of great service in minimizing the amount of organic matter in the distributed water, for the pollution of the rivers Thames and Lea is enormously increased during freshes, and if the companies could limit their intake to the periods during which the rivers were in their normal condition, they would have a far smaller initial degree of pollution to deal with. Unfortunately the area of storage reservoirs available is even in the case of the best provided company far too small to enable this result to be attained, and one water company has to draw from the river at all times. As regards the Thames, it has been shown by flood diagrams that fifteen to twenty days' storage properly worked will always enable water companies to reject flood water in spring and summer, but that it would be necessary for them to have eighty or ninety days' storage to enable them to exclude flood water in the autumn and winter.

The following appears to be the storage capacity of the reservoirs for unfiltered water belonging to each company, measured by the unit one day's supply:—

| | Days' supply. |
|---|---|
| East London | 17 |
| Chelsea | 14 |
| West Middlesex | 9 |
| Lambeth | 8 |
| New River | 6 |
| Grand Junction | 5 |
| Southwark and Vauxhall | 3 |

It is evident that most of the companies must use more or less flood water at all seasons, and that none of them are in a position to exclude such water in the autumn and winter except in a most trivial degree.

The seven companies drawing water from the Thames and the

Lea possess collectively filter-beds of an area of ninety-five acres. The material used consists of sand, fine and coarse gravel, and sometimes shells, arranged in layers; the finest, that is to say the sand, at the top, the coarser at the bottom of the bed. The thickness of sand varies from two to three feet, and the total thickness from three feet six inches in the case of the East London works to eight feet in that of the Chelsea Company. The rate of filtration generally adhered to is 540 gallons per square yard of filter-bed each twenty-four hours, and the surface layer of sand is scraped off and renewed when the reduction of the rate of filtration gives evidence of the clogging of the sand.

Comparative analyses of the raw and filtered water have shown that the process of filtration as practised results in removing from fifteen to thirty per cent. of the dissolved organic impurities. It usually renders the water clear and transparent.

Dr. Percy Frankland has pointed out in a paper recently read before the Society of Arts that Bacteria have been found in water which had passed through a properly prepared filter consisting of 100 feet thickness of sand, and as allowance has moreover to be made for imperfections in the process carried out on the enormous scale necessary for the supply of London, it seems clear that the passage of the sewage-tainted river water through the filter-beds affords no sufficient guarantee of its purity.

Indeed, when we consider the nature of the pollutions to which the Thames and the Lea are subjected, the vigour and persistency of the poisons which at times exist in excremental matters, and the astoundingly minute quantities of the specific poisons which suffice to produce disease, we cannot but experience a feeling of entire distrust in the efficacy of the so-called self-purification of flowing water, or of the artificial processes which have just been described. The view that water for domestic use should be above suspicion, and therefore obtained from a source incontaminable with sewage and like matters, is one which recommends itself to the common sense of all.

## CHAPTER VIII.

### GEOLOGY AND HYDROLOGY OF THE THAMES BASIN.[1]

Areas of Thames and Lea basins—Areas of permeable and impermeable outcrops—Upper Thames basin—Areas of outcrops of various formations—Length of Thames—Dip of formations and order in which traversed—Formations south of London—General conditions governing behaviour of water in contact with geological formations—Accumulation of water within permeable formations—Outflow and travel within rocks—Level of saturation—Rise of surface within hills—Separation of stores of water by impermeable strata—Effect of hydrostatic pressure—Effect of droughts—Storage capacity of a formation—Distinction between water retained by capillary attraction and that held up by impermeable beds—Capacity of chalk for holding water—Springs feeding Thames and its tributaries—Amount of dry weather flow—Description of general features of geological formations in Thames basin—The Bagshot sands—The London clay and lower tertiaries—The chalk and upper green sand—The gault—The lower green sand—The Portland stone and sands, Kimmeridge clay, coral rag, calcareous grit and Oxford clay—The great oolite—The inferior oolite—Discharge from the oolite beds into the Thames—Tributaries of the Thames—Tributaries of the Lea—Rainfall and percolation—Discharge of the Thames—Discharge of the Lea.

THE basin of the Thames, including that of its tributary the Lea, is upwards of 5000 square miles in extent; that of the Lea alone, about 500 square miles. The former includes within its area 170 square miles of lias, 931 of oolites, 5 of Hastings' sand, 13 of Weald clay, 453 of green sand and gault, 2096 of chalk, and 915 of tertiary deposits. Rather more than half, including the oolitic, cretaceous, and portions of the tertiary formations, is covered by a porous soil upon a permeable water-bearing stratum, and the greater portion of this area is cultivated; the remainder, occupied by the Oxford, Kimmeridge, Gault, and London clay, is covered by a clayey soil upon a stiff impervious subsoil, and the area is for the most part pasture and permanent meadow.

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[1] Report of Royal Commission on Water Supply, 1869. Sixth Report of Royal Rivers Commission. De Rance, Water Supply of England and Wales. Prestwich Water-bearing Strata of London. Geological Survey Memoirs, vol. iv.

The basin of the Thames above the intakes of the water companies comprises 3676 square miles, of which two-thirds are permeable, and includes 1047 square miles of chalk, 211 of Bagshot sand, 126 of upper green sand, and 327 of great and inferior oolite. The greatest length of the Thames from Trewsbury Mead to the estuary is 201 miles; from Lechlade, in Wilts, where it first assumes importance, to Ditton, where are the intakes of the water companies, its length is 120 miles. From the Cotswold Hills, where the Thames and its upper tributaries take their rise, to London, the various strata have a south-easterly dip and crop out at the surface in succession, so that in proceeding from the head waters to the metropolis we pass from older to newer formations, and each formation dips and passes under the one succeeding it. We thus find in succession the lias, the inferior oolite, Fuller's earth, great oolite, cornbrash and forest marble, Oxford clay, coral rag, Kimmeridge clay, lower green sand and gault, upper green sand and chalk, and finally the lower tertiary sands and the London clay. Amongst these the lias, Fuller's earth, forest marble, Oxford clay, Kimmeridge clay, Gault and London clay are classed as impermeable, while the remainder are permeable. The rainfall in the upper basin of the Thames amounts to about twenty-eight inches annually.

To the south of London an upheaval, the axis of which runs about east and west, together with denudation, has brought to the surface the Hastings sand and Weald clay, and caused the chalk of the North Downs and the underlying gault and green sand to dip gently towards the north. In passing from the Weald of Kent to London we cross in succession newer formations ranging from the Hastings sand to the London clay. To the north of London the strata have a south-easterly dip, and the general character of the geological strata of the district around London is that of a basin or trough, modified, however, by a few smaller and more local lines of disturbance.

We may here briefly note the general conditions which govern the behaviour of water in rock formations. When rain falls on impermeable strata, it collects on the surface, and runs off by means of the water-courses; when it falls on permeable formations, a considerable proportion sinks in. A portion of the supply is held up in the pores of the rock by capillary attraction, and the remainder gravitates downwards. Its motion is resisted by the friction it experiences in passing through the strata, or, on the other hand, it may be favoured by fissures. It proceeds until its progress is interrupted by some underlying impermeable formation, and then accumulates at the base of the pervious stratum, by the outcrop of which it entered. Accumulation proceeds, and the level of saturation rises until the water finds an exit, and effects a discharge which balances the receipts. The method of discharge is infinitely varied by circumstances. The term impermeable is used only in a relative sense, and does not imply that the underlying formation is absolutely water-tight, so that percolation may proceed, although at a greatly reduced rate. If the strata have a dip, the water will travel along the dip plane towards a lower level. When the level of saturation has risen so that it is above the surface of the ground at any part of the outcrop of the permeable formation, the water will flow out, forming springs. This outflow will occur in valleys at levels considerably below that of the outcrop, where the supply of water from rain enters the permeable strata; and in this case the head of water is often considerable and the discharge large. Streams are thus formed, which flow through the valleys. Faults which bring an impermeable stratum into contact with a permeable stratum may interrupt the flow of water down the dip plane, and cause an overflow at the surface. The plane of saturation dips towards the points of discharge in a variable curve. When two parallel valleys penetrate and drain a water-bearing formation, the surface of saturation in the spur between the valleys, representing the water level at every point, has the shape of an inverted trough or basin, rising towards the axis of the spur, and sloping towards the points of spring discharge in the valleys. In the Thames basin the crown of the water level often rises from 50 to 200 feet or more above the permanent spring levels in the valley. Where, as is the case in the Thames basin, bands of permeable and impermeable strata alternate, each porous band contains a separate body of water confined by the impermeable layers above and below. If the area of discharge by springs and down the dip of a stratum is not sufficient to carry off the water as fast as it is received, it rises within the stratum until the rock is full to the roof formed by the upper impervious layer. The hydrostatic pressure exerted reacts on the outlets, and increases the discharge, or fresh outlets are obtained by the rise of level. There is thus a constant sympathy between the supply, the head, and the expenditure of the water. If hydrostatic pressure is exerted on the impervious roof of a water-bearing formation, and such roof is pierced by a well or vertical fissure, or if it yields to the pressure, the water rises towards the surface; and if the head or pressure is sufficient, it will attain the surface of the ground, or even, if confined in a pipe, rise above it. It will at any rate rise until the gravity of the column of water, plus the friction, is sufficient to balance the hydrostatic pressure. Such cases of overflow are evidently likely to occur in troughs or basins formed by geological disturbance, when the outcrop of the permeable strata forms the sides or lip of the trough or basin, and the bottom is covered by the impermeable formation.

During droughts, or when, as in the summer, the percolation of rain water ceases to take place, the level of saturation in the water-bearing strata falls gradually, and the flow of the springs as gradually diminishes. If the advent of a fresh supply of water to the strata is sufficiently delayed, the springs fail, those on the highest level being the first to cease their flow. The storage capacity of a formation, measured by its power of keeping up the flow of springs without replenishment, varies greatly with its physical structure. Strata which store water in fissures and caverns deliver it more quickly than those which carry it evenly distributed throughout their mass, and fail more rapidly. Chalk, under favourable circumstances, maintains the flow of springs for many months. Mr. Beardmore estimates that the storage capacity of the chalk of the Lea basin is represented by sixteen months' spring flow. In prolonged summer droughts, as for instance in 1868, when many impounding reservoirs supplying towns failed, the Thames has maintained its ordinary flow.

The storage capacity of a rock formation may be more correctly described as proportional to the cubical capacity of its interstices per unit of volume. Mr. de Rance has, in his work on the water supply of England and Wales, given a good illustration of the meaning which is intended to be conveyed by the term. If we fill a bucket completely with gravel, or coarse sand, we shall still find that we can pour into the bucket in addition a certain amount of water without overflow taking place. The water occupies the interstices between the particles of gravel or sand. If we now pierce a number of holes in the bottom of the bucket, water will flow out, but not as much as was poured in. A certain quantity will cling to the gravel or sand. The quantity retained is that required to satisfy capillary attraction; that which flows out represents the proportion available for the supply of springs and wells. A cubic yard of chalk will admit within its structure fifty-four gallons of water; so that a mass of the chalk formation, one square mile in area and 100 yards thick, would hold 16,727,040,000 gallons of water. As already observed, a considerable proportion of the water so stored is not available for delivery by springs or into wells, as it is held by capillary attraction; but assuming that a permeable formation is already charged to the extent required to satisfy capillarity, the amount of rain percolating annually over the outcrop will be a measure of the quantity for delivery, or which, theoretically speaking, can be annually abstracted.

A portion of the water passing by percolation into the several permeable formations occurring in the upper Thames basin, and held up by the impermeable beds subjacent in each case to some one or more water-bearing strata, is thrown out at the levels of the streams and rivers forming the Thames and its tributaries, and in fact the summer flow of the Thames, which, in the driest season, never falls below 350,000,000 gallons a day at Thames Ditton, and rarely amounts to less than 500,000,000 gallons a day, represents the dry weather leakage, so to speak, of the enormous subterranean reservoir represented by the water-carrying capacity of the mass of permeable strata in the basin.

The following is a description of the general features of the formations occurring in the Thames basin :—

The Bagshot sands are from 100 to 350 feet thick, and extend over an area of 211 square miles. They consist almost entirely of loose quartzose sand, and the underground water oozes out commonly at their junction with the London clay, and is rarely conducted into any channel of escape so as to form springs. There are no springs of importance, and the supply to wells is not large. The water is generally soft and pure, but sometimes ferruginous. The whole of the water now delivered by them passes into the Thames or the Wey, none passes underground. The London clay underlies the Bagshot sands, and forms an impermeable bed from 400 to 500 feet thick. Mr. Bateman, C.E., has estimated that from 7,000,000 to 8,000,000 gallons a day of excellent water could be collected from this formation for use in London, but at somewhat disproportionate expense. The lower tertiary sands are only from 50 to 100 feet thick, and are of no importance so far as springs are concerned at their outcrop. Under London, owing to the number of deep wells, the level of water in this formation has been greatly lowered, and the underlying chalk is now generally resorted to. The chalk, from the large area of its outcrop, which is 1047 square miles above Kingston, and from its peculiar lithological character, forms the most important water reservoir in the whole of the Thames basin. Almost all the rain falling upon its surface is absorbed, and it takes weeks and even months to filter down to the level of the surface of saturation in the interior of the chalk hills. The Rivers Pollution Commissioners in their sixth report state that the deep well water from the chalk ranks amongst the best and most wholesome with which they had become acquainted, and that the chalk constitutes magnificent reservoirs, in which vast volumes of water are not only rendered and kept pure, but stored and preserved at a uniform temperature of about 50° Fahrenheit, so as to be cool and refreshing in summer, and far removed from freezing in winter.

The water stored escapes by numerous springs feeding the streams and larger rivers flowing through the chalk district, and it furnishes an important supply to wells. Mr. Harrison found in September, 1865, that the upper Thames received from the chalk over which it flowed 80,000,000 gallons a day. The upper green sand which succeeds the chalk, although permeable and holding water, is unimportant near London.

The upper green sand is separated from the lower green sand by 100 to 200 feet of gault clay. The lower green sands form a mass of silicious sandy strata from 200 to 500 feet thick, with an outcrop of about 500 square miles, part of which is to the north-west and part to the south of London. From Bedfordshire on the one side, and Reigate on the other, they dip towards London and disappear under the gault, but they do not appear to be continuous. In fact, it has been shown by boring, that they do not exist under Kentish Town. They were found by a boring in Tottenham Court Road at a depth of 997 feet, but in too compact a state to carry a water supply, and they are absent at Crossness Outfall Works, as was proved by the sinking of a well 1060 feet deep. It is supposed that they thin out against a ridge of palæozoic rocks, which, there is reason to believe, extends from Belgium towards Somersetshire, passing under London. Where they do exist outside London, they form a valuable and copious water-bearing bed. The quality of the water is excellent for all domestic purposes; generally soft, and free from organic matter. In some of the more stony beds there are fine springs.

The strata which succeed are only developed in the north and north-west of the London basin. The Portland stone and sands, the Kimmeridge clay, the Coral rag and Calcareous grit, and the Oxford clay, being either of small importance for water supply, or impermeable, need not be further noticed. The great Oolite and subordinate beds form an important group of permeable strata with a collecting area of about 300 square miles, and in Oxfordshire they are from 250 to 300 feet thick. They give rise to a number of springs, most of which are thrown out by the Fuller's earth.

The inferior oolite and underlying sands resting on the lias, form another important water-bearing formation. They extend in the Thames basin over an area of about 180 square miles, with a thickness of from 300 to 320 feet, and supply important springs. In the oolite strata the water passes chiefly by fissures, and is not so well filtered as in the chalk. The quality of the water is excellent for drinking, but hard. The hardness is, however, nearly all removable by liming.

The oolitic beds thin out to the eastwards, and probably die out in Oxfordshire, the Lias, Oxford, and Kimmeridge clays closing in. They could not, therefore, be reached by wells near London. One-third of the average Thames winter discharge is derived from the oolites above Oxford, and only one-eighth of its summer discharge.

The Thames above the intakes of the water companies is fed by thirteen tributaries, viz. on the north the Churn, the Coln, the Windrush, the Evenlode, the Churwell, the Thame, the Colne. On the south the Ray, the Cole, the Ock, the Kennet, the Loddon, and the Wey. Below the intakes there are, on the north, the

Yedding, the Brent, the Lea, and the Roding; on the south, the Hogsmill, the Wandle, the Ravensbourne, and the Darent. The main stream is navigable, nominally to Lechlade, but practically not beyond Oxford. Between Cricklade and Gravesend, eleven canals form junctions with the Thames.

The upper Lea and its tributaries are fed by springs from the chalk. The main stream enters the London clay district near Hoddesdon, about twenty six miles above its junction with the Thames. The tributaries are, on the north, the Mimram, the Beane, the Rib and Quin, the Ash; on the east, the Stort and Salmonbrook, and Cobbins brook. The streams entering below the water companies' intake on the west are, Turkey Street brook, Salmon brook, and Moselle. The Lea is tidal from the Thames to Lea bridge, a distance of five miles. It is navigable for barges to Hertford, a distance of twenty-eight miles. On the Stort, the navigation extends thirteen and a half miles.

Assuming the area of the upper Thames basin above the pumping stations of the water companies to be 3676 square miles, and the annual average rainfall 27·2 inches, the total yearly precipitation is represented by, in round numbers, 1,500,000 million gallons. The total quantity carried away by the Thames each year averages 493,850 millions gallons; the average daily discharge is about 1350 million gallons, or in the year somewhat over nine inches of rainfall. It has been assumed that in general terms one-third of the rainfall is carried away by the river, half in floods and half by spring flow, represented by a daily dry weather flow from 600 to 700 million gallons at Ditton. The Thames is also fed by numberless springs below London, which issue from the chalk.

The area of the Lea basin is about 500 square miles, and the mean annual rainfall twenty-five and a half inches. The average daily flow past Fields Weir is 108·8 million gallons. The summer flow in dry years averages 45·2 million gallons daily, including the supplies to the water companies. This does not more than suffice to meet the demand for London water supply and lockage.

# CHAPTER IX.

## VARIOUS SCHEMES FOR THE SUPPLY OF LONDON WITH POTABLE WATER.

Mr. Bateman's scheme—Position of gathering ground—Route of water-channel—Capacity of reservoirs—Amount of supply, quality, and cost—Comparison with other towns—Opinion of Commission of 1869—Objections to the scheme—Scheme of Messrs Hemans and Hassard—Position of gathering ground—Area and estimated supply—Length of channel to London—Collateral supply to other towns—Cost of scheme—Opinions expressed—Mr. Hamilton Fulton's project—Position of gathering ground—Length of channel to London—Capacity of reservoirs—Cost—Mill Dale scheme—Projects of supply from the Thames and its tributaries—Mr. McClean's scheme—Mr. Bailey Denton's plan—Its cost—Messrs. Brown and Bravender's project—Mr. Mylne's proposal—Proposal to utilize store of water in chalk and oolites—Views of the Rivers Pollution Commission—Calculation of amount of water available—Probable effect of pumping on general water-level—Best arrangement of wells.

THE foregoing brief sketch of the geology and hydrology of the Thames basin will enable the reader to appreciate fairly the arguments used in support of the various schemes for the supply of water to the metropolis, which have been referred to in the first chapter of this work.

Mr. Bateman, in introducing his scheme for bringing water from South Wales, urged the great advantages of a supply of exceptionally soft water in lieu of the hard water of the Thames, and suggested that the river supply was diminishing, and was not calculated to meet in the future the wants of the rapidly increasing and already enormous population of London. He considered, moreover, that the available supply in the chalk was small. Mr. Bateman proposes to use as a gathering ground certain areas of high land lying to the south of Snowdon and to the east of

Plynlimmon and Cader Idris, and which supply the head waters of the Severn. One of these areas comprises the drainage ground of five streams, tributaries of the Severn, viz. the Tylwch or Dalas, the Clywedog, the Carno, the Ceryst and the Tarannon, called the Southern District. Another includes the upper drainage grounds of the rivers Vyrnwy and the Banw, which, after combining, join the Severn between Welshpool and Shrewsbury. This is distinguished as the Northern District.

For the southern district a main reservoir at Trefeglwys is to be constructed, and also subsidiary reservoirs in other parts of the area. Other reservoirs are to be constructed on the various streams in the northern district, and the main collecting reservoir is at a point above Rhyd y Gro.

A separate conduit is to lead the water from each district, uniting at Marten Mere near Montgomery, and thence it is to be carried southwards by an aqueduct crossing the Severn near Bridgnorth, and passing near the towns of Stourbridge, Bromsgrove, Henley in Arden, Warwick, Banbury, Buckingham, Aylesbury, Tring, Berkhampstead, and Watford, where it is to be received into large reservoirs proposed to be constructed near Stanmore, about ten miles north-west of London. The total distance the water would have to be brought by conduit and aqueduct is a little above 180 miles. The aqueduct is to be capable of delivering 230 million gallons daily. The level of the head of the conduit is as designed to be about 450 feet, and the reservoirs at Stanmore about 270 feet above the sea. These last are to contain 2000 million gallons of water, or about 14½ days' consumption at the present time. There is to be constant service, and the reservoirs of the existing companies are to be used as far as possible.

| | Square Miles. |
|---|---|
| The area of the northern drainage is . . . | 104 |
| That of the southern . . . . . . . | 100 |
| Total . . . | 204 |

The drainage areas are, however, capable of extension so as to include 183 square miles. Mr. Bateman estimates sixty inches of rain for the driest year's absorption, and evaporation at twelve inches, leaving forty-eight inches; and again deducting 25 per cent. for safety, calculates on thirty-six inches as the available proportion of rainfall on which to base his calculations. For compensation to the rivers whose drainage basin was interfered with, he allows one-fourth of the supply, and on the above data he calculates on a supply for London of 111,000,000 gallons per day from the northern district, and 108,000,000 gallons from the southern district, or a total of 219,000,000 gallons. Mr. Bateman's estimate of the rainfall available from the district was, however, disputed by various engineers of eminence. Mr. Hawkesley estimated it at twenty-four inches instead of thirty-six inches, and Mr. G. Symons, Mr. Rawlinson, C.E., and Mr. Hassard, C.E., also thought it too high.

Mr. Bateman proposes to place in the northern drainage district four reservoirs, with a total capacity of 3,494,000,000 cubic feet, and in the southern district three reservoirs, containing collectively 3,215,000,000 cubic feet, giving a total of 140 days' supply, at 300,000,000 gallons a day, or more than double the present rate. The maximum height of embankments is to be eighty feet, and one of the reservoirs would have held 50 per cent. more than Loch Katrine. The quality of the water obtainable is in respect of purity and softness excellent,[1] although at times liable to become slightly discoloured by peat. As regards cost, Mr. Bateman's scheme is of an expansive character, susceptible of being gradually developed, *pari passu*, with the increase of the population of London, by extending the drainage area, and the arrangements for collecting, and to some extent also storing the water. Of course the main aqueduct and the individual reservoir embankments would have had to be constructed of full dimensions at the outset, so that for the smaller supply the cost was proportionately greater than for the larger supplies. The estimates of cost for various quantities are as follows:—

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[1] 2½ to 4½ grains per gallon of solids, and one to two degrees of hardness, Clarke's scale.

| | | |
|---|---|---|
| 130 million gallons | . . . . | £8,685,006 |
| 170 ditto | . . . . | 10,571,615 |
| 200 ditto | . . . . | 10,822,474 |
| 230 ditto | . . . . | 11,400,023 |

These sums include the arrangements for conveying the new supplies to the existing reservoirs of the Water Companies, but nothing for the purchase of the existing works or interests.

Capitalizing the then (1865) net revenue of the seven water companies drawing water from the Thames and the Lea, viz. 450,000*l.*, at twenty-five years' purchase, and adding thereto the cost of the first instalment of supply, Mr. Bateman deduces a total expenditure of 19,850,000*l.* for 130,000,000 gallons daily, or a cost per million gallons of daily supply of 165,416*l.* Similarly for a full supply of 230,000,000 gallons daily, the cost would be 100,454*l.*; comparing this with other towns, he shows that the cost was per million gallons daily at

| | |
|---|---|
| Liverpool . . . . . . . | £120,606 |
| Glasgow, limited supply . . . | 59,200 |
| Ditto full ditto . . . . | 33,643 |
| Manchester . . . . . . | 60,000 |

The rateable values of the two last cities in 1865 compared with London was as follows:—

| | Total assessable value. | Assessable value for Dwelling-houses. |
|---|---|---|
| Glasgow . . | £1,200,000 . . | £600,000 |
| Manchester . . | £1,200,000 . . | £600,000 |
| London . . | £15,000,000 . . | £10,000,000 |

These calculations, based on financial statistics nineteen years old, contrast in a striking manner with the figures of the present day. The net income of the seven water companies referred to by Mr. Bateman was, for 1882, 856,757*l.*, and the total assessable value of Metropolitan London (in December, 1883) 28,785,428*l.* The Commission on Water

Supply of 1869 state in their report that they believe Mr. Bateman's scheme to be practicable in an engineering point of view; but that the estimates of costs, not being based on detailed surveys, could not be relied on. They point out that if it were carried out, pumping could not be entirely dispensed with, and refer to the liability of the water to colorization by peat as an objectionable feature. The danger arising from the action of the soft water on lead pipes is also noticed. Mr. Bateman's estimate of rainfall they consider somewhat excessive, and it has been shown from a study of the rain registers at Greenwich for a period of fifty-six years that observations extending over half a century, and carried out at various parts of a district, are necessary in order to arrive at an exact knowledge of possible minima during a year or group of years. Other objections noticed are the interference with local interests by the abstraction of the water and the certainty of the most strenuous opposition to the scheme, the danger of having so large a population as that of London dependent solely on one source of supply, liable to interruption by accident, design, or frost, and the risk incidental to the presence of enormous reservoirs at the heads of important and populated valleys containing large towns.

There can, however, be no question that a large supply of excellent water could have been secured to the metropolis by Mr. Bateman's scheme, and at any rate the failure of the administration to carry out the recommendations of the Royal Commission of 1869 for the immediate purchase of the water companies' undertakings has resulted in a lamentable sacrifice of the public interests.

The proposal made by Messrs. Hemans and Hassard for supplying the metropolis with water, and which was examined by the Commission on Water Supply of 1869, is somewhat similar in principle to that of Mr. Bateman. Their proposed gathering ground is in the Lake District at a distance of 240 miles from London. The lakes dealt with lie to the north of the range of hills running between Scaw and Shap Fells. They are three in number—Thirlmere, Ullswater, and Hawes Water. The level of the water in the first is 533 feet, of the second 480 feet, and of the third 694 feet above the sea. The outlets of the two higher lakes were to be dammed up so as to raise their levels, Thirlmere by sixty-four feet, and Hawes Water by forty-two feet. The drainage water from neighbouring hills was to be turned into them by intercepting conduits, and the water from the two lakes was to be conducted by conduits and tunnels into Ullswater. This lake was to be tapped at its southern end by a tunnel under Kirkstone Pass, debouching on the slopes of the hills above Windermere, whence the water was to gravitate through a conduit to London. The quality of the water is excellent, subject, however, to the objection of occasional peaty discoloration, as in the case of the Welsh water. The total area of the collecting ground is 177 square miles, exclusive of the southern slopes of the hills, which formed a possible additional area of fifty-three square miles. The estimate of annual rainfall was based on the average of three dry years by 1853, 1854, and 1855, giving a mean of sixty-four inches. From this nine inches were deducted to represent loss by evaporation, leaving fifty inches available for water supply, which on an area of 177 square miles is equivalent to 350,000,000 gallons per day. Sixty-three million gallons per day were reserved to furnish compensation to rivers of which the drainage was to be intercepted, and the balance of 287,000,000 gallons represented the supply available for the metropolis and other towns. Ullswater was to be raised five feet, and the whole available storage, including certain auxiliary reservoirs, amounted to 5,563,000,000 cubic feet, equal to 120 days' supply at 250,000,000 gallons a day. The conduit was to carry a body of water represented by a river thirty feet wide and ten feet deep, flowing at the rate of about 1¼ miles per hour for a distance of 270 miles. It was to terminate in a large reservoir to be constructed near Edgware, at a distance of about twelve miles from Cumberland Gate, Hyde Park, and a height of 232½ feet above mean tide level. It was to contain fifteen days' supply at 250,000,000 gallons a day. Pumping would have been necessary for elevated districts about London. A part of the project consists in the supply of about 50,000,000 gallons daily to towns in Lancashire, the Potteries, and Midland Counties, and with this view an additional aqueduct seventy miles in length was proposed, joining the main aqueduct at Stoke with a reservoir at the point of junction. The estimated cost for bringing 250,000,000 gallons a day to London was 13,500,000*l.*, and the projectors estimated the cost of purchasing the existing water companies' works and interests at 8,500,000*l.* Mr. Hawkesley, however, on the basis of twenty years' purchase of the net revenue in 1867, which was 500,000*l.*, calculated the value roughly at 10,000,000*l.* The correctness of Messrs. Hemans and Hassard's estimate was impugned by Mr. Bateman on strong grounds, that gentleman stating it as his opinion that the cost of the works for 250,000,000 gallons would, on the most favourable view, be not less than 19,000,000*l.* sterling.

It has been admitted by competent authority that Messrs. Hemans and Hassard's plan is practicable, but also that the same objections exist to it as to Mr. Bateman's project, except that probably the local opposition would be less formidable. The appropriation of distant sources of supply, which geographically belong to other districts, has been noted as inadvisable, if it can be avoided.

Mr. Hamilton Fulton's project consists in the collection of water from the upper sources of the Wye. He selects four districts on the Wye and its tributaries, with a total area of 440 square miles, and calculates on a net average daily supply of 393,000,000 gallons. In his upper district there were to be six impounding reservoirs yielding 173,000,000 gallons daily. His conduit to London was to be 180 miles long, and his service reservoir at Barnet, eight miles from London, 276 feet above mean tide level. The estimate for the supply of 230,000,000 gallons amounts to 9,000,000*l.* A suggestion was brought before the commission for the collection of water on the Derbyshire hills at a point above Mill Dale on the River Dove, 586 feet above the sea, and its conveyance to Barnet, and thence to London. This source was, however, considered better adapted for the supply of manufacturing towns near it.

The difficulty of making calculations regarding the quantity of water which could be relied on from given districts in seasons of minimum rainfall, and the storage capacity to be provided in reservoirs to prevent failure in the supply, was brought prominently before the commission, and numbers of instances, as at Liverpool, Newcastle-on-Tyne, Bristol, Manchester, Rochdale, Bury, Preston, Kendal, Newcastle, Bradford, and Halifax, were given where such failures had occurred.

Various proposals have been made for the supply of the metropolis with unpolluted and wholesome water from the Thames and its tributary streams. Mr. McClean, C.E., M.P., in his evidence before the Duke of Richmond's Commission on Water Supply, in 1867, advocated the embankment and canalization of the Thames above Medmenham. He calculated that there would thus be formed a series of impounding reservoirs 2000 acres in extent, with an average depth of ten feet, and containing 5,000,000,000 gallons, or twenty-five days' supply of water, at a cost of 1,500,000*l.* Mr. Bailey Denton's plan involves the utilization of the upper streams of the Thames basin, on the supposition that the water could, by the exercise of strict conservancy, be obtained there in a condition of positive purity, and he concluded that by means of storage reservoirs a sufficient supply could be obtained to furnish a compensatory supply to the streams during the dry season. The sewage is to be excluded from the streams used, partly by intercepting drains leading to a point below the intake, and partly by causing it to be pumped up and distributed overland, which would absorb it. The Thames, and Severn, and the Wiltshire canals are to be purchased and used for the collection of the water above, and a conduit 127 miles long is to lead the water from Lechlade to London. The cost of the works is roughly estimated at 5,320,000*l*. Similar arrangements are proposed for the upper basins of the Lea, the Mole, and the Wey, the total supply being estimated at 200,000,000 gallons daily. Messrs. Brown and Bravender suggested the collection of the springs at the upper sources of the Thames, in order to furnish a separate supply for drinking only. The oolites are said to yield on the north side alone of the Thames, during the summer, 70,000,000 gallons daily of the purest water.

It is to be observed that neither Mr. McClean's nor Mr. Bailey Denton's scheme excludes water resulting from the surface drainage of the populated valleys, and more or less fouled by manured fields, and soakings from middens, ashpits, cesspools, farmyards, &c.

It is by no means established that sewage can be safely allowed to soak into a porous subsoil in the vicinity of springs which are utilized to supply drinking water, and that Mr. Bailey Denton's scheme for thus disposing of the sewage of places situated within the catchment basin of the upper tributaries of rivers from which water is drawn for domestic use would not result ultimately in the pollution of the water at its source.

Mr. Mylne proposed to collect the springs and chalk streams which form the upper Lea and its tributaries, and transfer the water to reservoirs at Enfield Chase, the quantity so dealt with being estimated at 43,000,000 gallons daily. Other supplies from a tunnel on the line of conduit, from springs such as those at Chadwell and Hoddesden, the latter pumped into the New River, and from the Rib, brought the total supply to 70,000,000 gallons, which were to be substituted for the present supplies of the New River and East London Companies. This scheme would certainly give the East London Company a purer supply than at present, and would perhaps improve the New River water also; but the utilization of the chalk streams by cuts leading from the Lea proper, the Mimram, the Beane, and the Rib, which are all exposed to pollution, since they pass through populated and cultivated valleys, renders this scheme unsatisfactory from the point of view of those who object on general grounds to such sources of supply.

The schemes of Mr. Thomas Hennell for bringing 14,000,000 gallons by the Basingstoke Canal, and that of Mr. Telford McNeil for pumping 200,000,000 gallons from the Thames at Teddington Lock, raising it from 200 to 380 feet, conveying it to the Bagshot Sands for filtration and thence back to London, require but passing notice.

A knowledge of the capacity of the oolites, and particularly the chalk for holding water, and the vast areas of other permeable formations exposed within the Thames basin around London, together with the evidence afforded by the flow of copious springs, has led many persons to the conclusion that in this store of subterranean water would be found the solution of the problem of the London water supply.

The Commission on Water Supply of 1869 laid much stress on the great value of the permeable strata around London in connection with the storage of water for the supply of London. Observing that one-sixth of the rainfall on the upper basin was delivered in the shape of springs forming the summer flow of the Thames, and which maintained their supply during the driest seasons, they add that it is satisfactory to know that there exists within easy reach of London a supply of the best and purest spring water, which in case of need could be made available with readiness as an auxiliary source of supply for the metropolis in quantity sufficient at all events for drinking, if not for other purposes.

This view was endorsed by the Rivers Commission in their sixth report, dated 1874, with the difference that they considered the quantity available ample for all purposes. They adopted the estimate founded on experiments by Mr. Graves, C.E., of six inches' absorption of rainfall on the average over the permeable formations, and on this basis they calculated that the subterranean reservoir received annually within a radius of fifty miles of London a supply of 187,000 million gallons of water, corresponding to a daily supply of 512,000,000 gallons. This represents the quantity which, it is supposed, escapes yearly by springs at various levels and flows into streams or rivers, or issues in the bed of the sea or estuary. The northern portion of the area supplies 145,000 million gallons, corresponding to a daily supply of 398,000,000 gallons, and is derived from 1,067,000 acres, which drain into the Thames and its tributaries, the Wye, the Coln, and the Lea; and the southern portion 42,000 million gallons annually or 115,000,000 gallons daily from 308,000 acres draining into the Thames by the Lodden, the Wey, the Mole, the Darent, and the Medway. A similar calculation, limited to the area of the chalk within thirty miles of London, indicates that a quantity represented by 202,000,000 of gallons daily is the theoretical maximum available.

The Commissioners suggested that by pumping from the subterranean reservoir in the autumn, when the springs begin to fail, the level of the reservoir would be lowered below the point where it ceases to supply the springs, and would thus be in a condition to store a larger proportion of the winter rain than it could otherwise have held.

The supply from the present springs would be thus artificially supplemented during the summer and autumn by pumping, and the water supply from the reservoir more uniformly distributed throughout the year.

They proposed to sink a number of wells below the present spring heads of the district, and draw constantly from them. They admitted that water so drawn would *pro tanto* diminish the streams fed by the chalk reservoirs, but urged that the requirement of quality was met by such an arrangement.

The view that the chalk would deliver to deep wells an ample supply of water for the metropolis was supported by Mr.

Homersham, C.E., and Mr. E. P. W. Barlow, C.E. The fact that the Kent Company has supplied from deep wells for many years a large population, and that the nine or ten wells available can be pumped to the extent of 14,000,000 gallons daily, and farther that the eight wells of the New River Company are capable of yielding a supply of ten or twelve million gallons per day, favours the opinion that large quantities of water can under favourable circumstances be obtained in this manner from a limited area. Nevertheless the experience gained by pumping from wells under London has shown that in certain cases the supply may be partly exhausted and the water level depressed many feet by the withdrawal of a not very large supply.[2] Mr. Lucas has proved by his investigations that the water level in parts of London has been lowered in some places as much as eighty feet during the past sixty years, the total pumped daily being estimated at from ten to twelve million gallons. It is asserted that the chalk under the London clay is of a denser character, and consequently of a smaller water-bearing capacity than that outside the clay. It is clear that the effect of every well, or group of wells, must be, so long as pumping goes on, a depression of the water surface in the vicinity. The ground drained by a well is, roughly speaking, an inverted cone of which the apex is the bottom of the well, and the base is a circle at the level of the surface of saturation. The sloping sides of the cone represent the inclined surface of the water flowing in all directions to the well. As the pumping proceeds, the depleted area or base of the cone extends, and the gradient down which the water travels becomes less steep, the resistance from friction tends to become equal to the component of gravity in the direction of the well, and the flow of water to cease. On the cessation of pumping, and if a sufficient interval of time is allowed, the depleted mass, represented by the cone, is replenished from more distant sources, but the general level of saturation is everywhere lowered. The whole effect of pumping and supply to a well is of course immensely complicated by variations in the permeability of the saturated formations, the occurrence of fissures, the cutting off or isolation, more or less complete, of masses of strata by faults, and the dip and flexures of stratified formations. Under favourable circumstances the rate of inflow towards a well from distant points may be so rapid and copious that the withdrawal of vast supplies of water by pumping produces but slight lowering of the water level; in other cases the supply is comparatively scanty and slowly delivered. In every case pumping must effect the lowering of the general level of saturation throughout the formation which communicates with the well, and the effect in reducing the head or pressure which causes the outflow of springs must be universally felt throughout the formation in which there is intercommunication by water flow. The effect of the proposed scheme of the Rivers Commission for lowering the level of saturation of the chalk during the autumn, with a view to increasing its storage capacity during the winter, would necessarily result in a general reduction of pressure due to head of water, and a falling off in the inflow to wells and outflow of springs, together perhaps with injurious aridity in certain tracts now scantily supplied.

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[2] Report of Institute of Surveyors, 1878.

## CHAPTER X.

### GENERAL CONCLUSIONS.

Acceptance of premise necessary preliminary to profitable discussion—Alternative modes of securing a pure supply of water—Derivation from a distant catchment basin—Derivation from water-bearing formations in Thames basin—Importance of combined action—Delegation of work to a central authority necessary—Functions of central authority—Responsibility of water companies in regard to purity of supply—Causes of their financial prosperity—Case of the water companies against the consumers—Case of the consumers—Essential conditions for securing effective legislation.

THE main object of this paper has been to state in logical sequence the principal facts and arguments which lead to the condemnation of the chief sources of the present water supply of the metropolis by many and probably by most educated people who study the question. Until and unless this view is accepted, it is useless to search for other sources of supply, or to discuss projects for utilizing them. If the waters of the Thames and the Lea are pure and wholesome, or if they can be rendered pure and wholesome by any artificial processes which can be economically carried out, agitation on the subject of the water supply in its sanitary aspect is at present baseless and idle, for the question of quantity is of no pressing moment. It has been shown[1] by satisfactory evidence that an increase of 50 per cent. in the actual daily intake from the Thames can be admitted and calculated on with perfect safety.

Instinct with the masses, and reading and reflection in the case of the educated, are, however, rapidly leading to a consensus of opinion regarding the entire unsuitability of rivers draining thickly-populated valleys for use as sources of water supply. It is hoped that the foregoing chapters may assist in bringing into definite shape vague and formless views on the subject which may exist in the minds of some, and that the ground may thus be cleared for united and determinate action. The object then in view will be the utilization of some one or more of the sources of pure water which are available, and a general consideration of the projects which have been already described, will probably lead to the conclusion that three modes of dealing with the problem are possible. One is to adopt the system of supply proposed by Mr. Bateman or Messrs. Hemans and Hassard, and conduct water to London from a distant and mountainous catchment basin; another is to thoroughly explore the chalk and other permeable formations within the Thames basin, and to sink deep wells and drive adits on a sufficiently extensive scale to supply the quantity required for daily use; the third is to limit the deep-well supply to the quantity required for drinking and cooking, while retaining the Thames and the Lea as sources of supply for baser uses, with all the complications of a double service. There is no doubt that defects may be pointed out in every project brought forward; but the policy which contents itself with counting up cost, defects, and difficulties, and ends by doing nothing when action is urgently necessary, cannot be defended.

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[1] Royal Commission on Water Supply of 1869.

In the lower valley of the Thames, probably the largest aggregation of human beings which the world has ever seen has to be dealt with, and the difficulties in securing the sanitary essentials of pure air and pure water are great and increasing. The provisions for drainage and water supply must be on a scale commensurate with the vast population, otherwise the poisons generated in the excretions and waste matters incidental to the habits of civilized man must, sooner or later, by causing disease or pestilence, prescribe sharply a limit to concentration. In short, schemes for dealing with sanitary difficulties in connection with the metropolis have to be measured by a standard of immense magnitude, in relation to which their dimensions, however large, become merely reasonable and suitable.

Viewed in this way, the proposals for impounding water in the mountainous districts of Northern England, or in Wales, and conveying it by conduit to London, appear to be reasonable, and they are undoubtedly practical in their character. Moreover, the magnitude of the proposed works, when compared with those of a similar character already in existence, is by no means startling. In India, the Ganges Canal, 654 miles in length, conveys 3348 million gallons per day for the irrigation of land in the North-West Province. The Baree Doab Canal is 469 miles long, with a discharge at its head of 1607 million gallons daily. The Western Jumna Canal is 445 miles long, with a discharge of 1339 million gallons per day. The Cavour Canal, in North Italy, has a daily head discharge of nearly 2081 million gallons, or more than eight times that of the proposed conduits to London. Its cost was 32,291*l.* per mile. Compared with these the proposed water conduit from Cumberland to London, 273 miles in length, and carrying only 250 million gallons daily, is a work of moderate dimensions. Its cost cannot be estimated with anything approaching accuracy, without a detailed survey of the catchment basins and the route of the channel; but if we assign 18,000,000*l.* sterling as a rough approximation to the sum necessary to cover the expenditure for bringing the water to the outskirts of London, this indicates a charge of about 5*d.* in the pound on the rateable value of property within the boundary of the Metropolitan Local Management Act, for payment of interest on the loan required. The water would suffice, however, for nearly double the population within the limits indicated, and the rate would be subject to reduction, whether by sale of water to the outer suburbs, or in the future by increase in the number of houses.

Manifestly if such a conduit were constructed by the ratepayers, securing a magnificent supply of the purest water, negotiations for the purchase of the distributing works of the London water companies would rest upon an entirely different basis from that adopted in 1880. Having no monopoly of supply, with works a considerable portion of which would be rendered absolutely useless, and the mere abstract value of which would be comparatively small, the shareholders would be in a very disadvantageous position, and, on the most favourable view of their claims to consideration, could hardly expect to receive such a sum as that demanded by them in 1880, which covered receipts, present and prospective, representing enormous returns on the capital actually expended by them, and in the calculation of which no account was taken of the grave depreciation in the value of the works, due to the pollution of the sources of supply which they were constructed to utilize. The above is a mere outline sketch of a possible phase of the water question. The objections urged to the schemes for utilizing distant gathering-grounds cannot be considered to be of such vital consequence as to prohibit the adoption of one of them, if nearer sources fail. Protection from the consequences of exceptional frost impeding the flow of water, resolves itself into a question of storage near London, and the dangers incidental to war or civil commotion have never prevented cities from depending for their ordinary supply of water on aqueducts traversing long distances. There exists, however, an obligation on the part of a community to utilize the supplies of pure water available within its own district, before it draws on sources which are in the neighbourhood of and may be equitably claimed for first use by other populations; and for this and other reasons the extension of the deep-well system of supply to the greatest possible extent, and, if it were possible, on such a scale as to satisfy the present requirements of London, is an alternative the prosecution of which with full vigour is much to be desired.

The considerations alluded to in the latter portion of the previous chapter lead to the conclusion that in order to obtain the required supply by deep wells, these should be widely distributed, and so placed as to intercept as much and as directly as possible the flow of the water to river and stream-feeding springs. The effect of pumping in lowering the level of saturation would then be reduced to a minimum, and the change from the present system would practically be the abstraction of the water required for London from many instead of three points in the basin, viz., Hampton on the Thames, Ponders End, and Ware on the Lea. The formation of storage reservoirs on the course of the streams above the points where they leave the impermeable formations which they cross, would readily furnish the means of delivering to the rivers, during the summer, of a supply of water to compensate for the intercepted spring flow, if such an arrangement should be found necessary.

It cannot be asserted that the proposals for the supply of London from deep wells are free from objections.

There can be no absolute certainty as to the yield of a well sunk in a given situation; and there is always the danger that, whether by the accident of fissures in the chalk, or leakage from the subsoil, the efficacy of the natural filtration, on which the quality of the water depends, may be interfered with. It is nevertheless certain that a very large supply of pure water can be secured in this manner within a moderate distance of London.

It is, moreover, a very favourable feature of the scheme for substituting deep-well water from the chalk, &c., for the river water, that it can be tentatively and progressively carried out. Unlike the vast projects for storage and conveyance of water for hundreds of miles, which, as regards the mass of the works, must be embarked on in their full magnitude, and completed before a trial can be made of their efficiency, each group of wells is a distinct unit of the project, which, if successful, can add its quota to the metropolitan supply, and if only employed to dilute the pollution of the river water by mixture in the service reservoirs, it will diminish the risk of injury to health. Failure in the case of any well or group of wells, owing to scanty flow of water, pollution from drainage entering by fissures or reversed flow from an adjacent stream or river, need not materially affect the general scheme.

A partial supply from this source, if such were the limit found attainable, need not interfere with the eventual prosecution of the project for obtaining water from Cumberland, or any such distant source; for in the present condition of the water supply of provincial cities and towns, and the general anxiety to obtain water of a satisfactory character, the sale of any surplus quantity brought down could readily be effected at intermediate points.

The proposal to rest content with a supply of pure water, sufficient for drinking and cooking purposes, does not recommend itself on examination. It would be a boon to the rich and well-to-do, but it would hardly reach or benefit the vast majority constituting the poorer classes. The difficulty in preventing misapplication and waste of what would be a precious commodity would be great. The duplication of the enormous ramification of distributing pipes, of establishments and charges, the introduction into the streets of another source of roadway demolition and repair, are strong objections. Probably in many cases the river water would still be drunk, and that without the previous precautions of filtration and the check of official analysis, which do palliate to a certain extent the danger.

It is evident that the immense extension of deep wells here contemplated would have to be carried out with discretion and in strict combination. The effect of well-pumping in lowering the water level sometimes extends over a large area, and rivalry in the depletion of the subterranean reservoir might lead to great waste of money. In respect of the spring and subterranean water available in the neighbourhood of the metropolis, Londoners are in the position of shipwrecked mariners on a raft. The stock of water is limited, and will have to be equitably distributed for the benefit of all. Local hoarding and exemption from the hardships of the common scarcity should not be tolerated, and in the event of its being necessary to seek a supply from distant sources, all localities within the extreme metropolitan radius should be contributories to the cost. Considerations such as these bring clearly into view the necessity for the constitution of a representative authority for the whole metropolis, including its suburbs, having plenary power to deal with the question of water supply. The postponement of united action for the settlement of this question until a central authority has been established under some such scheme as that of the London Government Bill brought forward this session (1884), implies the prolongation for an indefinite period of a state of things which may at any time, as in the event of an epidemic in the upper valley of the Thames, become intolerable. Pure, abundant, and cheap water for London is a platform which all without distinction of party or politics would unhesitatingly adopt, and there would probably be as little difficulty in carrying a rider that the Thames and the Lea are and must remain unfit for use as sources of supply of potable water for the metropolis. If such a basis of action were adopted by all local authorities, delegations could be sent to form a central body with a well-defined mission, and with authority which would be the less likely to be abused as its functions would be restricted within narrow limits, and would, moreover, be of a temporary nature. The work to be entrusted to such a body would be to obtain in the first place legislative recognition of its purpose and authority. Thereafter its duties would consist in carrying out the detailed examination of alternative schemes of water supply which are worthy of consideration. It would execute the detailed surveys and prepare the estimates of cost of these, or any one of them, negotiate with the water companies for the purchase of their undertakings on the basis of the condemnation of the present system of supply so far as derived from rivers, prepare a scheme involving the acquisition of the works and interests of the companies on an equitable valuation, and the execution of the selected project of derivation from a pure source of supply, and obtain the sanction of Parliament thereto. It would carry out negotiations with other towns or districts interested, and arrange for the adjustment of their claims to the sources of supply proposed to be utilized. The functions of such a body would naturally terminate with the completion of the works and the realization of the scheme, and it would hand over its trust to the central municipal authority, if such existed, or to any permanent water authority which might be constituted.

Preliminary and final condemnation of the present main sources of supply, and the knowledge that future valuations of their undertakings would take this fact into consideration, would constitute strong inducements to the water companies deriving from the Thames and the Lea, to place themselves with the least possible delay in the position of the Kent Company, whose deep-well water has hitherto stood the test of reasonable sanitary inquiry. Exploration of the water-bearing strata around the metropolis would in this way be carried out on a scale which would before long afford reliable data for an estimate of the quantity of water which could be daily abstracted from this source of supply.

The past history of the water question shows that nothing but organized and combined public action on the part of the inhabitants of London, resulting in legislative interference, will cause the water companies to incur the expense of changing their sources of supply.

Any change in the sources of supply from which the London water is derived would naturally entail further expenditure in works and machinery, and the question arises, how far the water companies can be equitably called on to incur this outlay, or how far the cost of such works should be set off against the asserted value of the companies' present works and interests, when negotiations for their purchase by the public are set on foot? The essence of their contract with the public is their obligation to furnish a supply of pure and wholesome water to all who may require it within reasonable limits as to distance and quantity. If it be assumed as an established proposition, that the Thames and the Lea cannot furnish pure and wholesome water, it would seem that the companies who now draw water from these rivers may reasonably be required to go to other sources of supply. That the companies have largely acknowledged and acted upon their obligation to furnish good water to their customers is evidenced by their heavy expenditure during past years in moving their pumping stations, constructing storage reservoirs, and enlarging their filters. They have, moreover, utilized spring water when available near their works, and in one instance, viz. that of the Kent Company, they have actually of their own accord abandoned a river supply and adopted the system of pumping from deep wells. On the other hand, transfer of the intakes of the companies from between the bridges to Hampton, and to Ponders End on the Lea, above the tidal influence, was carried out with the concurrence of the legislature, and the companies have some reason to urge that the responsibility for the present arrangements, and the loss which condemnation of the present sources of supply would entail, cannot with justice be entirely thrown upon them. This, however, is only one of the many questions of account between the public on the one hand, and the water companies on the other, which will have before long to be adjusted. The improvident legislation, exhibited in the framing of the special Acts which confer on the water companies their powers and privileges, has placed them in so advantageous a position that the value of their shares in 1880 as concurrently estimated by the government and themselves, amounted to 29,734,281*l.*, the value at par or capital originally invested being 8,959,728*l.* In other words, every 100*l.* of share capital was valued at somewhat over 331*l.*

The circumstances which united in conferring this extraordinary value on the shares of the water companies are briefly as follows:—

By their several special Acts they are entitled to charge on the annual value of the tenements which they supply, and in addition they are allowed to make extra charges for water closets, baths, high service, and to supply at agreed rates for other than domestic service. In 1880, when the Purchase Bill was under discussion, the companies read annual value to mean the gross rental paid by the tenant, and not the rental realized by the landlord, after meeting outgoings for repairs and maintenance of the premises, and this interpretation was not at that time disputed. The revenue of the companies has two main elements of increase,—*viz.* that due to the extension of the metropolis by building in the suburbs, and that resulting from the increase in the rental of houses.

In 1872 the number of houses supplied was 496,966, and in 1883, 654,102, showing an increase of 157,136 in eleven years.

The present rate of increase is apparently in excess of 20,000 houses per annum. The increase in the rateable value of houses has also been remarkable. In 1871 the valuation lists showed a rateable value of 20,049,742*l.*; in 1883 the rateable value was 28,785,428*l.*[2]

The companies have exercised their statutory powers, and raised their rates, but, as some of them assert, not to the full extent represented by the increase in the annual value of the houses within their several districts. In 1872, while supplying 496,966 houses, they received gross water rents amounting to 1,091,353*l.*, which represents a return per house of 44*s.* In 1879 they supplied 564,720 houses, with gross water rents of 1,431,574*l.*, representing a return of 50*s.* per house. In 1882 they served 633,102 houses, and demanded 1,648,275*l.*, or 52*s.* per house. The indication of increased charges furnished by these figures would doubtless be much more striking if an analysis of the accounts were prepared showing the water rents for successive years in the more central districts of the metropolis. The results are diluted by the incorporation of newly-rated houses of low value in the suburbs. The figures as they stand show, however, that the companies benefit by the increased value of houses, and that their charges increase in a manner which has no relation to the value of the supply of water.

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[2] For the metropolis included under the Metropolitan Local Management and later Acts.

The increase in the gross income of the companies is therefore not accompanied by a corresponding increase in the capital expenditure. In 1871, with an expenditure on capital account of 10,212,994*l.*, the net water rents amounted to 979,041*l.*, or 9·5 per cent. In 1879 the capital expenditure was 12,402,966*l.*, and the net water rents 1,375,570*l.* or 11·1 per cent. In 1882 the capital expenditure was 13,093,741*l.*, the net water rent 1,561,811*l.*, or 11·9 per cent. on the outlay. The net profit of the undertakings has largely increased of late years, and is still increasing. In 1871 the net profit represented 6·45 per cent. on the share capital; in 1879, 7·9 per cent.; in 1882, 9·0. In 1879, the year in which the negotiations for the purchase of the companies' works were concluded, the net profit amounted to 716,737*l.* In 1882 the net profit was 856,757*l.*, showing an increase in the net revenue of 140,020*l.* in four years.

The Water Works Clauses Act, 1847, so far as it relates to the limitation of profits to 10 per cent. on the paid-up capital, the formation of a reserve fund, and the final reduction of rates in the event of the profits exceeding the limit, seems to have been incorporated in the special Acts of the water companies; but their claim to back dividends under the 75th Section of the Act, to make up the deficiency of any previous dividend due prior to the passing of the Act, appears also to have been admitted in principle, inasmuch as a large payment in commutation of these back dividends formed an item in the purchase money proposed to be paid under the arrangement provisionally concluded in 1879 by the Secretary of State.

The water companies justified their demands for large compensation, not only on legal, but on equitable grounds. They pointed out that they, as private individuals, had come forward and stood in the gap, when no public body was willing to risk capital in order to supply a public want, that many families had invested money in the undertakings on the faith of the privileges conferred by the special Acts, and that they had laid out large amounts in works in advance of the actual requirements with a view to meeting future demands for water, and that much of this outlay had yielded up till now an insufficient return.

The representatives of the ratepayers and consumers ask for relief in respect of the water rates, and an improvement in their position relatively to the water companies, on the ground that the companies have no monopoly of supply, that the system of payment by annual value was adopted on the assumption that such values would be fairly proportionate to the relative quantities of water consumed, that annual value should in any case be understood to mean the net value as determined for poor-rate assessment, that supply by meter would afford a more equitable means of regulating charges, and should be available at the demand of the consumer, that the payment of back dividends should be limited so that the ratepayers might have a reasonable prospect of participating in the financial prosperity of the companies by a reduction in the charges, as was obviously intended by the Act of 1847, and finally it is asserted by a very large and increasing section that the larger portion of the water is derived from polluted sources, and that the necessary arrangements should be carried out for obtaining a pure supply.

The task of devising and giving practical effect to measures which will adjust in an equitable manner the legitimate claims of the water companies and the public is not an easy one, and effective legislation is not probable, unless there is a strong and persistent manifestation of public opinion on the subject, together with a legally constituted representative body to give that opinion unity and definite expression.

Five of the Water Companies close their accounts on the 31st of March and three on the 31st of December of each year. In lumping the results, therefore, it has been necessary to sum, as if for one and the same period, the transactions of three companies for twelve months ending 31st of December, and of five companies for twelve months ending the 31st of March following. This system is followed in the Official Analysis, the year quoted being to 31st of December.

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